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Intraoperative Neurophysiological Monitoring in Total Hip Arthroplasty for Crowe Types 3 and 4 Hips

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Background: Crowe types 3 and 4 dysplastic hips usually need total hip arthroplasty (THA) with femoral shortening osteotomy (FSO) to facilitate reduction, equalize limb length, and decrease the traction stress in nerves. The frequency of peripheral nerve palsy after primary THA has been reported to range from 0.08% to 3.7%. Apart from direct trauma to the nerve, the excessive extension of the extremity is also reported as a common cause of nerve damage. The current study aimed to evaluate the outcomes of intraoperative neurophysiological monitoring (IONM) in THA for Crowe types 3 and 4 hips.

Methods: The data of patients who underwent primary THA with IONM were retrospectively reviewed using our medical records. Patients with Crowe types 3 and 4 dysplastic hips were included in the study. Motor-evoked potentials and somatosensory-evoked potentials were assessed intraoperatively. Preoperative dislocation height and postoperative trochanter minor differences were measured using preoperative and postoperative radiographs.

Results: Twenty-three hips of 19 patients (4 bilateral THAs) with a mean age of 45 years participated in the study. Ten hips (43%) were classified as Crowe type 4, whereas 13 hips (57%) were Crowe type 3. The mean preoperative dislocation height was 41.6 mm (range, 15–100 mm). Postoperatively, only 6 patients had a difference between trochanter minor levels with a mean of 8.5 mm (range, 3–17 mm). Three patients underwent a subtrochanteric FSO to achieve reduction. Postoperatively, no patient had any motor and sensory nerve dysfunction.

Conclusions: According to the results acquired from this study, no nerve palsy was observed after THA for Crowe types 3 and 4 hips, and subtrochanteric FSO was not performed in all Crowe type 3 hips and 70% of Crowe type 4 hips with the aid of IONM.

Keywords: *Total hip arthroplasty, Hip dysplasia, Neurophysiological neuromonitoring*

Total hip arthroplasty (THA) is a challenging procedure for developmental dysplasia of the hip, which can cause limb length discrepancy and coxarthrosis.1) Crowe types 3 and 4 dysplastic hips usually need THA with femoral shortening osteotomy (FSO) to facilitate reduction, equalize limb length, and decrease the traction stress in nerves.2,3) The frequency of peripheral nerve palsy after primary THA has been reported to range from 0.08% to 3.7%.4) Apart from direct trauma to the nerve, the excessive extension of the extremity is also reported as a common cause of nerve damage.5) Previously, some studies defined the use of intraoperative somatosensory-evoked potentials (SSEPs) as an early warning of nerve damage.6-8) In experimental studies, it has been shown that nerve damage can develop in > 6% elongation of the nerve.9) In their neuromonitoring study during THA, Bayram et al.10) evaluated the critical limit of lengthening and reported

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that nerve lengthening of 5% relative to femoral length is a critical value for nerve palsy.

Excessive stretching can cause ischemia by affecting vascular circulation in peripheral nerves; when nerve ischemia time is short and vascular circulation is restored, nerve conduction cannot be affected. Kennedy et al.[8] found that the nerve amplitude decreased, the latency was prolonged during retraction, and nerve conduction returned to normal after retraction was stopped. In 2019, Kong et al.[11] reported the outcomes of neuromonitoring use in THA for Crowe type 4 hips. They performed a step-by-step approach according to the presence of alert signals intraoperatively, and by the guidance of neuromonitoring, they could achieve a safe and efficient lengthening of the extremity.[11] We utilized the same approach since September 2019 and routinely perform intraoperative neurophysiological monitoring (IONM) for Crowe types 3 and 4 hips to detect any injury to the nerves and the need for FSO to avoid nerve palsy. By using neuromonitoring in THA, we decreased the number of FSO for Crowe types 3 and 4 hips.

The current study aimed to evaluate the outcomes and efficacy of IONM in THA for Crowe types 3 and 4 hips. We hypothesized that IONM can reduce the incidence of postoperative nerve palsy and lower the number of additional subtrochanteric FSO procedures to prevent nerve palsy.

METHODS

Study Population

This retrospective study was performed under the approval of the Institutional Ethical Review Board of Istanbul Atlas University (Aug 27, 2021; No. 6986) and conducted according to the Declaration of Helsinki. Informed consent was obtained from each patient. The data of patients who underwent primary THA with IONM between September 2019 and January 2022 were reviewed using our medical records. By Crowe classification,[12] the radiographic classification of dysplastic hips was performed using preoperative pelvis anteroposterior radiographs. Patients with Crowe types 3 and 4 dysplastic hips were included in the study. The exclusion criteria were Crowe types 1 and 2 hips (15 hips), posttraumatic hips (3 hips), and dysplastic hips with high-riding greater trochanter that cannot be accurately classified according to Crowe classification (7 hips).

Nerve Monitoring and Surgical Technique

For the monitoring of motor-evoked potential (MEP), needle electrodes were inserted in a sterile fashion into the tibialis anterior muscle, vastus lateralis muscle, gastrocnemius muscles, and flexor hallucis muscles. SSEPs were obtained by stimulating the posterior tibial nerve with 13-mm flat-bottom (subdermal) electrodes. The NIM Eclipse Nerve Monitoring System (Medtronic Inc., San Diego, CA, USA) was used for nerve monitoring, which includes 10 channels of MEP and 4 channels of SEP. After the implantation of the electrodes into the hemispheres, the baseline values were recorded before the procedures. A 50% decrease in the SEP or MEP amplitudes or a 10% increase in SEP latency was defined as being indicative of nerve dysfunction.[13] IONM was performed by the same technician (BB) (Fig. 1).

All patients were operated on under general anesthesia (propofol and remifentanil regimen) in lateral decubitus position with a standard lateral Hardinge approach by the same surgeon (KT). The hip capsule was opened from the anterior, and the femoral neck was cut after the hip joint was dislocated. The original acetabulum was detected via the exploration of the transverse acetabular ligament and the inferior of the capsule. The iliopsoas tendon was routinely cut in Crowe types 3 and 4 hips. Gluteus maximus release from femoral attachment, percutaneous adductor tenotomy, hip external rotator release from femoral attachment, and rectus femoris release was performed if needed. The acetabulum was prepared with a 35°–45° of inclination and an appropriate anteversion by taking into account the combined anteversion and preserving the medial wall as much as possible. Combined cup and stem anteversion in THA based on femoral anteversion was used to compensate for abnormal femoral anteversion in

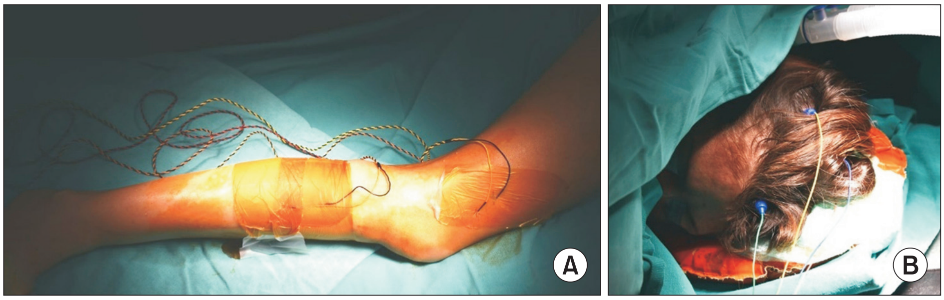

Fig. 1. Photographs showing the placement of sterile needle electrodes to the extremity (A) and the placement of four percutaneous electrodes to the skull (B) for bilateral hemisphere monitoring.

dysplastic hips. The autografts harvested from the femoral head were impacted to the acetabulum via reverse turning of the reamer, especially for Crowe type 4 hips that usually have a lower bone stock. A cementless acetabular cup was implanted in the reamed acetabular area according to the planned size. The cup was secured with two or three screws, and a polyethylene insert was implanted in the cup. Femoral preparation was performed after the exploration of the proximal femur. A prophylactic cerclage wire was implanted in the proximal femur to prevent a fracture in the dysplastic femur if necessary. The trials were performed with trial femoral components and trial heads. For unilateral cases, the lengthening of the extremity was planned according to the preoperative shortening; for bilateral cases, the lengthening in the second procedure was performed according to the index procedure. After the achievement of proper lengthening, neuromonitoring testing was performed to compare with base levels. The lengthening was achieved by changing either the femoral head size (XS/-3 to XL/+12) and/or the femoral stem. Subtrochanteric FSO was performed in three patients in whom reduction could not be achieved despite all soft-tissue releases. After the femoral canal preparation, a transverse subtrochanteric osteotomy was performed 2 cm below the level of the trochanter minor. A 35-mm bone block was distracted and divided into two parts to place around the osteotomy site as an autograft, and the two-part bone block was fixed with a cable. A non-cemented femoral component was implanted in the femur and the planned head (Oxinium or metal) was placed on the femoral component. The hip was reduced and checked for the range of motion and the safe zone for luxation. A neuromonitoring test was applied after the implantation of the prosthesis. MEP and electromyography test results were recorded, printed, and documented in each patient. After the closure of the wound, the last test was applied, the electrodes were removed, and the neuromonitoring ended (Fig. 2).

Before incision After implantation of prosthesis

Fig. 2. The intraoperative neurophysiologic monitoring reports that had been documented intraoperatively demonstrated a decrease in motor-evoked potential amplitudes < 50%.

Data Evaluation

Patient demographics (age and sex) and body mass index-

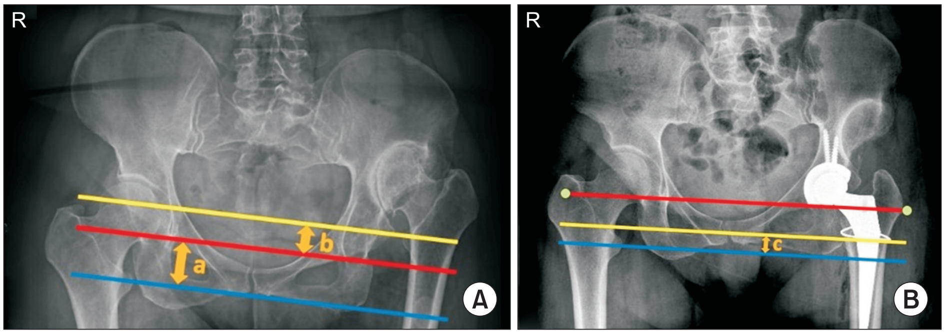

Fig. 3. Measurement of hip dislocation height in preoperative (A) and postoperative (B) pelvis anteroposterior radiographs. Red line: inferior teardrop vertical line, Yellow line: the vertical line drawn from the tip of the lesser trochanter of the operated hip, Blue line: the vertical line drawn from the tip of the lesser trochanter of the unoperated hip. The distance between the yellow and blue lines represented the dislocation height. Thus, the sum of "a" and "b" is equal to the preoperative dislocation height of the left hip, and "c" is the postoperative difference in the hip heights.

es (BMIs) were noted using our medical records. Standing full-length radiographs (orthoroentgenogram) were taken preoperatively and postoperatively. Measurements were performed using our Picture Archiving and Communication Software (Medware PACS) by two senior authors of the study (MK and YC). Digital radiography images have a ruler to prevent errors during measurement due to magnification. High intraobserver (intra-class correlation [ICC], 0.91; 95% confidence interval [CI], 0.87–0.96) and interobserver (ICC, 0.86; 95% CI, 0.81–0.91) reliability was observed in the measurements. Limb length discrepancy due to the femur and tibia was assessed by measuring the distance between the tip of the greater trochanter and the center of the talus. The length of the femur was evaluated by measuring the distance between the tip of the great trochanter and the distal femoral joint line. The preoperative dislocation height was evaluated by measuring the distance between the horizontal lines of the inferior teardrop and the tip of the trochanter minor (Fig. 3). The postoperative difference between trochanter minors was also assessed using postoperative radiographs. The difference between these measurements was defined as the total lengthening of the extremity.

All patients' range of motion, as well as muscle

Table 1. Demographics and Main Clinical Characteristics of the Patients

Patient	Age (yr)	Sex	BMI (kg/m^2)	Height (cm)	Length of femur (mm)	Side	Prior hip surgery	Crowe classification	Femoral shortening osteotomy (mm)	Preoperative dislocation height (mm)	Postoperative hip height difference (mm)
1	48	F	26.2	160	440	L	No	4	No	61	17
2	49	F	25.4	160	420	R	No	4	No	NA	0
	49	F	25.4	160	420	L	No	4	No	NA	0
3	49	F	27.3	160	390	R	No	3	No	NA	0
	49	F	27.3	160	390	L	No	3	No	NA	0
4	48	F	30.4	157	420	R	No	3	No	NA	0
	48	F	30.4	157	420	L	No	3	No	NA	0
5	57	F	23.2	158	370	R	No	4	Yes, 35 mm	71	10
6	33	M	19.8	165	390	L	No	3	No	26	3
7	26	M	29.2	155	420	L	No	3	No	25	4
8	56	F	43	160	410	R	No	4	No	19	0
9	60	M	24.3	188	510	R	No	3	No	29	9
10	40	F	25.8	165	430	R	No	3	No	24	0
11	26	F	23.2	164	400	R	Yes	4	No	26	0
12	35	F	28	158	440	L	No	4	Yes, 40 mm	100	0
13	60	F	31	158	420	R	No	3	No	48	0
14	52	F	36.9	150	390	L	No	4	No	40	0
15	51	F	30	165	440	R	Yes	3	No	18	0
16	39	F	35	147	430	L	No	3	No	15	0
17	44	F	27	157	420	R	No	3	No	NA	0
	44	F	27	157	420	L	No	4	No	NA	0
18	54	M	27	179	460	R	No	3	No	32	0
19	44	F	24	163	440	R	Yes	4	Yes, 35 mm	45	8

BMI: body mass index, L: left, R: right, NA: not applicable.

strengths of the entire lower extremity, was routinely assessed at each follow-up that was set at postoperative 1st, 3rd, 6th, and 12th months and annually thereafter. All medical and operative complications were recorded. The mean follow-up time was 16.7 months (range, 6–24 months).

Statistical Analysis

Only descriptive analysis was performed to calculate means and standard deviations using IBM SPSS ver. 26.0 (IBM Corp., Armonk, NY, USA).

RESULTS

Twenty-three hips of 19 patients (15 women and 4 men) with a mean age of 45 ± 9.6 years (range, 26–60 years) participated in the study. Four patients underwent sequential bilateral THA with 2 days intervals. The mean BMI was 27.7 ± 4.7 kg/m^2 (range, 19.8–36.9 kg/m^2). Three patients had a history of failed open reduction for the treatment of developmental dysplasia of the hip. Ten hips (43%) were classified as Crowe type 4, whereas 13 hips (57%) were classified as Crowe type 3. The mean preoperative dislocation height was 41.6 ± 25.5 mm (range, 15–100 mm).

Postoperatively only 6 patients had a difference between trochanter minor levels with a mean of 8.5 ± 5 mm (range, 3–17 mm). Table 1 summarizes the main clinical characteristics of the patients. Postoperatively, the mean hip flexion was 107.6° ± 9.8°, the mean hip extension was 10.2° ± 5.9°, the mean hip internal rotation was 17.6° ± 4.7°, the mean hip external rotation was 19.3° ± 5.5°, the mean hip abduction was 30.4° ± 5.8°, and the mean hip adduction was 29.1° ± 8.5°. All muscle strength in the lower extremity was 5/5, which means that muscle function is normal and can function when maximum resistance is applied.

Neurophysiological events occurred in 6 of 23 THA sessions. Temporary signal changes were seen in MEP traces either during reduction of the prosthesis (4 cases) or positioning of the extremity during acetabular preparation (2 cases). These artifact-like signal changes can be defined as signals that resolved after checking again due to the relaxation of the muscles. Three patients (patients 5, 12, and 19) underwent a subtrochanteric FSO to achieve reduction restricted by soft-tissue tightness without any signal changes (Fig. 4). Postoperatively no patient had any motor and sensory nerve dysfunction. One patient had mild paresthesia in her thigh (patient 1), which resolved in the second postoperative month.

Aside from this study, we were curious about our rate of subtrochanteric FSO for Crowe types 3 and 4 hips and reviewed our medical records 2 years before using IONM. We observed that we performed FSO in all patients with Crowe type 4 hips (10 patients–10 hips) before using IONM. Likewise, FSO was not performed for Crowe type 3 hips before using IONM.

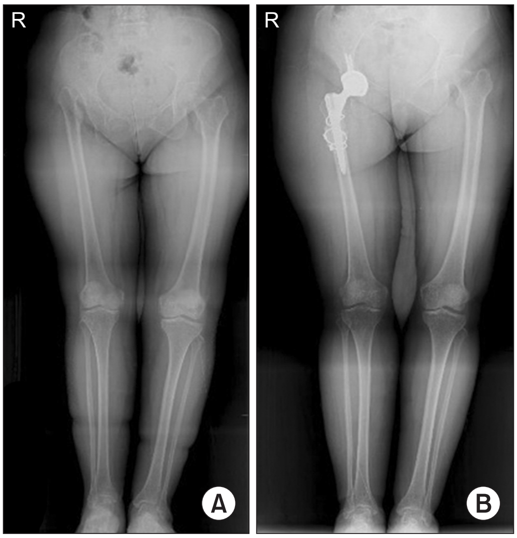

Fig. 4. Preoperative (A) and postoperative (B) full-length standing radiographs of patient 5 who underwent femoral shortening osteotomy to achieve reduction.

DISCUSSION

The most important finding of this study was observing no nerve palsy after THA in patients with Crowe types 3 and 4 hips, despite performing FSO in only 3 of 23 hips (13%). In 3 patients with Crowe type 4 hips, the FSO procedure was added to THA to facilitate the reduction. In summary, 70% of Crowe type 4 hips did not need an FSO procedure to prevent the occurrence of nerve palsy with the help of IONM. Our null hypothesis can be accepted that IONM reduced the rate of subtrochanteric FSO in the THA procedure for Crowe type 4 hips and prevented the occurrence of postoperative nerve palsy. Kong et al.[11)] evaluated the outcomes of IONM during THA for unilateral Crowe type 4 hips and observed no nerve palsy in their neuromonitoring study group despite performing FSO in only 6 of 35 patients (17%). The authors[11)] observed 10% nerve palsy in their no neuromonitoring control group despite performing FSO in 59% of patients.

Bayram et al.[10)] evaluated the safe limit and critical limit for the lengthening of the extremity in their IONM study and observed that the safe limit for lengthening was

3% of the femoral height and the critical limit was 5% of the femoral height. Johanson et al reported that the nerve palsy ratio was 28% when > 4 cm lengthening was performed during THA regardless of femoral length.5) There is no limit in the literature for the safe limit and critical limit of lengthening of the extremity in Crowe types 3 and 4 hips; hence, FSO is recommended as a safe procedure and performed on a traditional basis according to the soft tissue and sciatic nerve tension.14) In the current study, when we did not consider the 3 patients who underwent FSO, the mean lengthening was approximately 5% of the total femur length (432.5 ± 38.4 mm). Our result is consistent with the current literature, and it reveals the advantage of IONM in reducing the FSO procedure as well as preventing nerve palsy.

The sciatic nerve and femoral nerve are both at risk during THA, especially in complex cases such as high-riding hips and previously operated hips. Pereles et al.15) assessed the preoperative and intraoperative SSEPs during THA and found that anterior and lateral retraction of the femur caused signal changes in eight patients (15%). Previously in 1989, Nercessian et al.16) also remarked on this issue in their study evaluating the intraoperative SSEPs for the sciatic nerve in revision hip arthroplasties; they encountered signal changes in 8 patients (32%). Intraoperative neurophysiological testing is recently more popular in THA via the direct anterior approach. Wang et al.17) found in their intraoperative electromyography study assessing the femoral nerve that placing the acetabular retractors in one- and two-o'clock positions (right hip) may increase the risk for nerve palsy. Ishimatsu et al.18) also reported MEP signal changes during the placement of retractors to the anterior acetabular wall. The authors of a recent review mentioned that the routine use of IONM is still debated, but the use of IONM can be recommended in selected cases such as dysplastic hips in which the nerve injury risk is 10 times higher.19,20) Our results also demonstrated the advantages of IONM in Crowe types 3 and 4 dysplastic hips in preventing nerve palsy and also eliminating additional FSO procedures, which we performed before to prevent nerve palsy.

This study has several limitations. First, its retrospective design and limited cohort number are the main limitations. However, we retrospectively analyzed a prospectively followed cohort that was closely followed up in a single center. Another limitation of our study is the absence of a control group. The explanation of this issue is our routine use of IONM in THA operations, and we only have had a chance to review our previous data before using IONM. The main strength of the present study is being the second study after the study of Kong et al.11) that remarked on the advantage of using IONM in eliminating the FSO procedure for Crowe type 4 high-riding hips.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Yoon PW, Kim JI, Kim DO, et al. Cementless total hip arthroplasty for patients with Crowe type III or IV developmental dysplasia of the hip: two-stage total hip arthroplasty following skeletal traction after soft tissue release for irreducible hips. Clin Orthop Surg. 2013;5(3):167-73.
2. Sofu H, Kockara N, Gursu S, Issin A, Oner A, Sahin V. Transverse subtrochanteric shortening osteotomy during cementless total hip arthroplasty in crowe type-III or IV developmental dysplasia. J Arthroplasty. 2015;30(6):1019-23.
3. Talwar J, Agarwal S, Agarwal S, Krishna LG, Rustagi A. Step-cut subtrochanteric osteotomy combined with total hip arthroplasty for neglected traumatic hip dislocations. Clin Orthop Surg. 2022;14(2):205-12.
4. Farrell CM, Springer BD, Haidukewych GJ, Morrey BF. Motor nerve palsy following primary total hip arthroplasty. J Bone Joint Surg Am. 2005;87(12):2619-25.

5. Johanson NA, Pellicci PM, Tsairis P, Salvati EA. Nerve injury in total hip arthroplasty. Clin Orthop Relat Res. 1983;(179): 214-22.
6. Black DL, Reckling FW, Porter SS. Somatosensory-evoked potential monitored during total hip arthroplasty. Clin Orthop Relat Res. 1991;(262):170-7.
7. Stone RG, Weeks LE, Hajdu M, Stinchfield FE. Evaluation of sciatic nerve compromise during total hip arthroplasty. Clin Orthop Relat Res. 1985;(201):26-31.
8. Kennedy WF, Byrne TF, Majid HA, Pavlak LL. Sciatic nerve monitoring during revision total hip arthroplasty. Clin Orthop Relat Res. 1991;(264):223-7.
9. Lewallen DG. Neurovascular injury associated with hip arthroplasty. Instr Course Lect. 1998;47:275-83.
10. Bayram S, Akgul T, Ozmen E, Kendirci AS, Demirel M, Kilicoglu OI. Critical limit of lower-extremity lengthening in total hip arthroplasty: an intraoperative neuromonitorization study. J Bone Joint Surg Am. 2020;102(8):664-73.
11. Kong X, Chai W, Chen J, Yan C, Shi L, Wang Y. Intraoperative monitoring of the femoral and sciatic nerves in total hip arthroplasty with high-riding developmental dysplasia. Bone Joint J. 2019;101(11):1438-46.
12. Crowe JF, Mani VJ, Ranawat CS. Total hip replacement in congenital dislocation and dysplasia of the hip. J Bone Joint Surg Am. 1979;61(1):15-23.
13. McLain RF, Saavedra FM. Intraoperative nonparalytic monitoring. In: Benzel EC, Francis TB, eds. Spine surgery: techniques, complication avoidance, and management. 3rd ed. Philadelphia: Elsevier/Saunders; 2012. 1701-3.
14. Palumbo BT, Salomon K, Sullivan A, Simon P, Lyons S, Bernasek TL. Total hip arthroplasty with subtrochanteric osteotomy for developmental hip dysplasia: a long-term follow-up study. Arthroplast Today. 2022;17:101-6.
15. Pereles TR, Stuchin SA, Kastenbaum DM, Beric A, Lacagnino G, Kabir H. Surgical maneuvers placing the sciatic nerve at risk during total hip arthroplasty as assessed by somatosensory evoked potential monitoring. J Arthroplasty. 1996; 11(4):438-44.
16. Nercessian OA, Gonzalez EG, Stinchfield FE. The use of somatosensory evoked potential during revision or reoperation for total hip arthroplasty. Clin Orthop Relat Res. 1989; (243):138-42.
17. Wang Q, Wang H, A G, Xiao T, Kang P. Intraoperative monitoring of the femoral nerve using free electromyography during total hip arthroplasty via the direct anterior approach. Bone Joint J. 2022;104(2):193-9.
18. Ishimatsu T, Kinoshita K, Nishio J, Tanaka J, Ishii S, Yamamoto T. Motor-evoked potential analysis of femoral nerve status during the direct anterior approach for total hip arthroplasty. J Bone Joint Surg Am. 2018;100(7):572-7.
19. Murena L, Colin G, Dussi M, Canton G. Is intraoperative neuromonitoring effective in hip and pelvis orthopedic and trauma surgery? A systematic review. J Orthop Traumatol. 2021;22(1):40.
20. Rogers BA, Garbedian S, Kuchinad RA, Backstein D, Safir O, Gross AE. Total hip arthroplasty for adult hip dysplasia. J Bone Joint Surg Am. 2012;94(19):1809-21.