Neuromonitoring in pre-post and intraoperative total hip replacement surgery in type 4 high-riding developmental dysplasia of the hip

A. TAHERIAZAM[1], S. BAGHBANI[2], M. MALAKOOTI[3], F. JAHANSHAHI[3], M. ALLAHYARI[1], A. DINDAR MEHRABANI[1], S. AMIRI[4]

[1]Department of Orthopedics, School of Medicine, Tehran Medical Sciences, Islamic Azad University, Tehran, Iran
[2]Sina Hospital, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran
[3]Faculty of Medicine, Iran University of Medical Science, Tehran, Iran
[4]Department of Orthopedic Surgery, Shohadaye Haftom-e-Tir Hospital, School of Medicine, Iran University of Medical Sciences, Tehran, Iran

Abstract. – OBJECTIVE: The choice approach to treating congenital dislocation of the hip joint is total hip replacement (THR). One of the severe but uncommon complications of THR is nerve damage. The most common nerve injury associated with total hip arthroplasty (THA) is sciatic nerve palsy, and the second typical nerve damage with THA is femoral nerve paralysis.

PATIENTS AND METHODS: In this prospective cohort study, 35 patients with type 4 high riding developmental dysplasia of the hip (DDH) who were candidates for THA were enrolled. The somatosensory evoked potential (SSEP), motor evoked potential (MEP), and electromyography (EMG) were measured pre-post and intraoperatively to check the status of the sciatic and femoral nerves. After collecting the mentioned information, the data was analyzed by SPSS V. 26 software.

RESULTS: Out of 35 patients with DDH type 4 who were candidates for THR, nine patients showed a 50 percent decrease in SSEP amplitude, and six patients showed a 10 percent decrease in SSEP latency. One patient during and two patients after the surgery showed more than an 80 percent decrease in MEP amplitude. Meanwhile, 14 patients showed abnormal spikes during and two patients after surgery regarding EMG. All patients with disturbed neurophysiological findings reverted to normal in the further investigation during follow-up. No correlation was found between increasing limb shortness and these modalities.

CONCLUSIONS: Using neuromonitoring techniques during Total Hip Arthroplasty (THA) can help identify potential early nerve damage, prevent post-surgical complications, and improve high-riding DDH patient outcomes.

Key Words:
Total hip replacement, Developmental dysplasia of the hip, Neuromonitoring.

Introduction

One of the most commonly performed and successful orthopedic surgeries for congenital dislocation of the hip joint is the total hip replacement (THR). This procedure aims to restore hip joint function and alleviate patient pain by replacing the damaged joint with an artificial one[1,2]. X-ray imaging is commonly used to assess the hip joint before surgery[3]. However, each surgical approach, such as the posterior approach popularized by Moore in the 1950s, has its own side effects, including leg length discrepancy, femur fracture, fusion defects at the osteotomy site, and nerve damage[4,5]. Nerve damage is a severe but rare complication associated with THR. Direct nerve damage can result from compression, stretching, traction, ischemia, rupture, or a combination of these factors. The weakness and pain caused by nerve damage can negatively impact patient outcomes[6].

Studies[7] have indicated that nerve injury may occur if the nerve is elongated by more than 6% of its length. Smaller patients with shorter legs and nerves may experience less neural elongation, which may partially explain gender differences in the prevalence of nerve deficits.

Sciatic nerve palsy is the most common nerve injury associated with THR, occurring in nearly ninety percent of nerve injuries. Patients with sciatic

Corresponding Author: Shayan Amiri, MD; e-mail: amiri.shay@iums.ac.ir

nerve damage may experience leg drop, posterior thigh pain, and paresthesia in the distribution of the sciatic nerve. Femoral nerve paralysis is another typical nerve damage observed with THR, characterized by internal paresthesia in the pelvis or front of the thigh. The reported incidence of nerve injuries ranges from 0.28% to 3%, but it increases to 7.6% in revision and complex THR cases[8,9].

Intraoperative multi-modal nerve monitoring, which includes electromyography (EMG), motor-evoked potentials (MEP), and somatosensory-evoked potentials (SSEP), has been widely used in spine, brain, nerve, and thyroid surgeries[10-16]. Some studies[14-18] have shown that this approach can reduce nerve damage in patients with high-level dysplasia. In our facility, board-certified neurologists specialized in neurophysiology have developed a perioperative multi-modal nerve monitoring method to evaluate sensory and motor pathways during orthopedic surgeries. This approach helps identify risk factors associated with increased nerve damage and prevent subsequent peripheral nerve injuries.

The aim of this study was to collect data from complex patients requiring significant femur lengthening, typically observed in DDH type 4 cases with more than 4 cm of shortening. We analyzed the data obtained by examining changes in amplitude, latency, and the occurrence of alarms during surgery. Furthermore, we sought to establish a correlation between the amount of primary limb shortening and the gathered nerve monitoring findings. Our objective was to determine whether utilizing nerve monitoring modalities in this manner could benefit these patients by preventing iatrogenic nerve damage. Additionally, the surgeon utilized a more cautious approach upon receiving alerts from these modalities during surgery to minimize the potential risk of direct nerve damage.

Patients and Methods

This prospective cohort study was conducted at the Department of Orthopedics of Azad University of Medical Sciences. We selected 35 patients with type 4 high-riding developmental dysplasia of the hip (DDH) who underwent total hip replacement (THR) between 2019 and 2020. Patients provided written consent, and all necessary tests were performed, which is outlined in the Ethics approval section.

Patients

Based on similar research and considering expected limitations and disease prevalence, the sample size was determined to be 35 patients using Stata version 11 software. Patients with high-riding congenital dislocation of hip type 4 who were candidates for primary THR and provided written consent were included. Patients with known underlying neurological and cardiac diseases, DDH type 1, 2, or 3, candidates for revision surgery, and non-cooperative patients were excluded. All included patients were available for follow-up within a predetermined time period.

The Surgical Procedure

Patients with type 4 DDH who met the inclusion criteria and provided written informed consent were included in the study. The surgeries were performed using the direct lateral approach under general anesthesia. Nerve monitoring was conducted before, during, and after surgery. Baseline values for somatosensory evoked potentials (SSEP), motor evoked potentials (MEP), and electromyography (EMG) were measured by a neuromonitoring team prior to surgery. Disposable needles were used to assess the status of the sciatic and femoral nerves. For this purpose, monitoring included EMG of Tibialis anterior, Extensor Digitorm brevis, Abductor hallucis, Vastus medialis, MEP through transcranial electrical stimulation and segmental muscle signal recording, and SSEP through peripheral stimulation of peroneal and tibial nerves and, in some patients, saphenous nerve using SCALP needles. EMG, SSEP, and MEP of the femoral nerve, including the quadriceps muscles. The contralateral limb served as a control in all patients. Data interpretation was based on a referenced article[10].

During surgery, continuous neuromonitoring was performed, and any irregular data indicating possible nerve damage triggered warnings to the surgeon. The neurophysiologist set alarms for significant changes in nerve monitoring, prompting necessary precautions and modifications to minimize nerve damage. In this study, alarms were triggered by MEP amplitude below 80%, SSEP amplitude below 50%, SSEP below 10% of baseline recordings, or silent waves in EMG recordings. Additional variables, such as the type of DDH and the amount of femur bone shortening, were also recorded.

Statistical Analysis

Data were analyzed using SPSS 22 (IBM Corp., Armonk, NY, USA). Descriptive statistics, such as mean, standard deviation, and relative frequency, were used for quantitative and qualitative variables. Paired sample *t*-tests were performed to compare SSEP and MEP amplitude and latency between phases. The sign test was used to investigate alarm signals from EMG, MEP, and SSEP data. The relationship between limb shortening and neuromonitoring results was assessed using odds ratios and correlation tests. Statistical significance was set at $p<0.05$.

Results

In this study, a total of 35 patients diagnosed with DDH type 4 underwent THR surgery between 2019 and 2020. Upon receiving alerts from the nerve monitoring team, the surgeon implemented the digastric osteotomy technique to reduce the incidence of sciatic and femoral nerve damage. Subsequently, a neurophysiologist assessed post-operative nerve conduction modalities to evaluate any neurological complications in each patient. The study included six male and 29 female participants, with a mean age of 39 years. On average, patients experienced a limb shortening of 5.94 cm, and the surgical procedures had an average duration of 2 hours.

Demographic data, including age, sex, shortening measurement, and the incidence of alarm rates observed by each monitoring modality during different phases (baseline, during surgery, and post-surgery), are summarized in Table I. Additionally, the neurophysiologist documented the occurrence of transient or permanent neurological damage of the sciatic or femoral nerve before, during, and after the operation. The nerve monitoring device detected disturbances in nerve function 31 times during surgery and 14 times after surgery. In response to the alerts, the surgeon adjusted their surgical technique and interpreted the changes observed in the nerve monitoring using the digastric osteotomy technique.

Table II provides detailed information on somatosensory evoked potential (SSEP) amplitude and latency, motor evoked potential (MEP) amplitude, and electromyography (EMG) alterations at different phases: baseline, during surgery, and post-surgery. At baseline recordings, one patient exhibited absent SSEP amplitude and latency, presumably due to complications from a prior hip replacement surgery in childhood.

Table I. Demographic view.

	Timing of Evaluation	Positive/ Negative	Frequency		Percentage %		Mean	SD
Sex			29 Female	6 Male	82.9 Female	17.1 Male		
Age (y)							39.11	9.56
Primary limb shortness (cm)							5.94	1.56
SSEP amplitude Alarms	During surgery	P	9		5.7			
		N	25		94.3			
	After surgery	P	6		17.1			
		N	28		80			
SSEP latency Alarm	During surgery	P	7		20			
		N	27		77.1			
	After surgery	P	9		25.7			
		N	25		71.4			
MEP amplitude Alarm	During surgery	P	1		2.9			
		N	34		97.1			
	After surgery	P	2		94.3			
		N	33		5.7			
EMG Alarm	During surgery	P	14		40			
		N	20		57.1			
	After surgery	P	2		5.7			
		N	32		91.4			

Somatosensory evoked potential (SSEP), otor evoked potential (MEP), and electromyography (EMG).

Table II. SSEP amplitude and latency, MEP amplitude, and EMG alterations.

	Timing of Evaluation	Mean (ms)	SD in comparison with baseline	N	*p*-value in comparison with baseline
SSEP amplitude	Baseline	0.99		34	
	During	0.72	0.42		0.001
	After	0.99	0.38		<0.001
SSEP latency	Baseline	37.98		34	
	During	30.99	1.28		0.001
	After	37.98	2.96		0.001
MEP amplitude	Baseline	368.2		35	
	During	362.1	51.01		0.485
	After	368.2	91.09		0.366
EMG	Baseline			Negative: 35 Positive: 0	<0.001
	During			Negative: 21 Positive: 14	
	After			Negative: 33 Positive: 2	0.50

Somatosensory evoked potential (SSEP), motor evoked potential (MEP), and electromyography (EMG).

During the surgery, the mean SSEP amplitude was 0.72 ms (a difference of 0.27 ms from baseline), and the latency was 30.99 ms (a difference of 6.99 ms from baseline). After the surgery, the mean SSEP amplitude was 0.99 ms (no difference from baseline), and the mean latency was 37.98 ms (no difference from baseline). In 26 patients, SSEP amplitude during surgery was within the average range, while in 28 patients, SSEP latency during surgery was average. However, nine patients during the surgery and six patients after the surgery showed a decrease of more than 50% in SSEP amplitude, and seven patients during the surgery and four patients after the surgery showed a decrease of more than 10% in SSEP latency, triggering the set alarm for the surgeon.

Regarding MEP amplitude, after evaluating the baseline values for each patient, the mean amplitude changes were 362.1 ms during the surgery (a difference of 6.1 ms from baseline) and 386.2 ms after the surgery (no difference from baseline). Thirty-four patients during the surgery and 33 patients after the surgery exhibited relatively average MEP amplitude. However, one patient during the surgery and two patients after the surgery showed a decrease of more than 80% in MEP amplitude.

Additionally, EMG assessment revealed that no abnormal findings were observed at baseline. However, during the surgery, 14 patients exhibited abnormal spikes in EMG, and two patients showed anomalous positive train after the surgery.

Since the exact data on nerve monitoring modalities could not be obtained for certain patients, a confirmatory sign test was conducted using the number of alarms received and analyzing the differences observed in each phase. The findings of this analysis are presented in Table III, which reinforces the same underlying observation. Thus, a correlation can be established.

Table IV provides a comprehensive overview of the differences and correlations observed between the degree of limb shortening and neurophysiological findings. There was no significant correlation between increasing limb shortening and SSEP amplitude (*p*-value during surgery=0.954, *p*-value after surgery=0.673) or SSEP latency (*p*-value during surgery=0.149, *p*-value after surgery=0.248). Similarly, MEP amplitude did

Table III. Each Neuro-monitoring modality's differences in time and their correlation.

	Timing	Differences	N	*p*-value
SSEP amplitude Alarms	During *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 9 25 34	0.004
	After *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 6 28 34	0.034
SSEP latency Alarms	During *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 7 27 34	0.016
	After *vs.* Baseline	Negative difference * Positive difference** Ties Total	0 9 25 34	0.004
MEP amplitude Alarms	During *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 1 34 35	Not applicable
	After *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 2 33 35	0.500
EMG Alarms	During *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 14 20 34	<0.001
	After *vs.* Baseline	Negative difference* Positive difference** Ties Total	0 2 32 34	0.500

Somatosensory evoked potential (SSEP), motor evoked potential (MEP), and electromyography (EMG). *Alarms during < Alarms base. **Alarms during > Alarms base.

Table IV. Alarms correlations with shortness of limbs.

	Time of evaluation	Correlation	Odds ratio	*p*-value
SSEP amplitude	Baseline During After	-0.092 -0.011 -0.078		0.603 0.954 0.673
SSEP latency	Baseline During After	-0.250 0.068 0.230		0.149 0.702 0.256
MEP	Baseline During After	0.039 0.028 0.049		0.822 0.872 0.782
EMG	During After		0.87 1.70	0.54 0.33

Somatosensory evoked potential (SSEP), motor evoked potential (MEP), and electromyography (EMG).

not exhibit a significant decrease during (*p*-value=0.822) or after (*p*-value=0.782) surgery.

Additionally, the Odds ratio analysis indicated that limb shortness had no significant effect on EMG findings during surgery (OR=0.873). However, increasing limb shortening was associated with a decreased rate of abnormal EMG findings after surgery (OR=1.703).

Furthermore, all patients who exhibited disturbed neurophysiological findings during and after surgery underwent follow-up neurological examinations during the recovery period, and all reverted to normal. This lack of correlation between observed data and long-term outcomes suggests that direct nerve injuries are rare and often the result of indirect mechanisms, with the exact etiology of the damage remaining unknown[6].

Discussion

Crowe grade 4 dysplastic hip in developmental dysplasia of the hip (DDH) refers to progressive radiographic changes in the Acetabular Angle, Cup Inclination, loosening, and ectopic formation that develop over a span of years[19]. Total hip arthroplasty (THA) involves significant reconstruction of the true acetabulum, resulting in improved hip biomechanics, function, and correction of limb shortening. However, restoring the affected acetabulum in more severe dysplastic hip conditions is associated with higher complications and failure rates compared to simpler total hip replacement (THR) procedures for milder dysplastic hips. It can also lead to increased limb length and pose a risk of additional traction-related neural damage, particularly affecting the sciatic and femoral nerves[20-23].

To mitigate these neurological consequences, some institutions employ multimodal intraoperative nerve monitoring techniques. SSEPs, introduced in the 1970s for electrical monitoring of sensory pathways during spinal surgeries, were found to be unreliable for assessing descending motor pathways[24]. In contrast, MEPs, which assess descending cortico-spinal tract evoked potential, have been introduced[25]. EMG is commonly used to assess the risk of intraoperative nerve injuries. However, relying solely on EMG for neural monitoring may carry a high risk of maintaining neural deficits, rendering it unreliable.

Combining these perioperative monitoring methods has shown promise in predicting and preventing iatrogenic sensory and motor complications in various types of surgeries. SSEP and MEP have demonstrated effectiveness and accuracy in detecting perioperative neurological injuries during spine and lumbosacral surgeries, potentially improving outcomes in complicated procedures involving nerve root injuries[26-28].

In a study conducted by Sutter et al[10] on different types of surgical actions in complex total hip replacement, which involved multimodal intra-operative monitoring (MIOM), 24 out of 69 patients developed nerve palsy, with one patient showing true positive due to congenital hip subluxation. Irregular baseline potentials were documented in 25 patients, which made interpreting changes during surgery less reliable, as the nerves were likely partially damaged pre-operatively. Based on their ten years of experience, the researchers concluded that using multimodal intra-operative monitoring during complex hip surgery effectively reduces the possibility of nerve injury[10].

In our current practice, we routinely employ perioperative nerve monitoring in patients with Crowe grade 4 DDH who undergo simple or complex THA. We hypothesized that sciatic or femoral nerve injuries are primarily associated with limb lengthening. Therefore, as the level of limb shortness increases, the surgeon must be cautious about limb lengthening, as it predisposes the patient to neural complications, particularly in DDH grade 4.

For this study, we selected 35 patients with grade 4 DDH who were candidates for THA. The mean limb shortening was 5.94 cm (ranging from 3 cm to 9 cm). Preoperative evaluations were performed to assess limb length, and multimodal nerve monitoring, including SSEP amplitude and latency, MEP, and EMG, was conducted before general anesthesia, during limb lengthening, and after surgery when patients were awake. The neurophysiologist alerted the surgeon when a potential nerve injury was estimated, and the surgeon modified the operation using digastric osteotomy to shorten the femoral shaft length until no further alerts were received from the monitoring device.

Following limb lengthening, nine patients showed diminished SSEP amplitude, seven showed diminished SSEP latency, and only six showed concordance between amplitude and latency. Additionally, one patient exhibited decreased MEP amplitude, and 14 showed abnormal amplitudes in EMG, indicating an alarm for potential nerve damage. Consequently, the surgeon was advised to modify femoral lengthening using digastric osteotomy to reduce traction.

After surgery, six patients showed diminished SSEP amplitude, nine showed disappeared SSEP latency, and two showed abnormal amplitudes in EMG and decreased MEP amplitude, suggesting the possibility of transient or permanent neurological impairment. Overall, the mean SSEP amplitude during and after surgery significantly decreased compared to baseline ($p<0.001$), and SSEP latency during and after surgery increased compared to baseline ($p<0.0001$). However, the comparison for MEP amplitude did not yield the same results (p-value for MEP amplitude=0.3 during surgery and 0.5 after surgery). Further evaluation of EMG differences showed a significant increase in EMG abnormalities during surgery ($p<0.001$), but no difference in EMG abnormalities after surgery ($p=0.5$).

These findings align with the analysis of the alarming rate from each modality, indicating that disrupting somatosensory tracts during total hip arthroplasty in DDH grade 4 is more common, although motor functions assessed through MEP show relatively fewer changes. After one month of recovery, all functional neurological examinations returned to normal, indicating that the neural impairments observed were transient, and the positive results from all modalities after surgery were false positives. SSEP during surgery was more sensitive than MEP in alerting the surgeon to modify the THA plan and reduce the risk of subsequent neural damage. On the other hand, EMG analysis during surgery, which requires active muscle contraction while patients are unconscious, was not a reliable modality. However, when consciousness is regained, combining MEP and EMG could relatively assist in diagnosing neuromuscular impairments.

To explore the association between limb shortness and nerve monitoring variables, we conducted additional tests. The final results suggested no correlation between nerve monitoring modalities and limb shortness. It can be concluded that despite the increasing tension applied by the surgeon to more shortened limbs, the amount of neural damage is independent of that tension. Intraoperative nerve monitoring and modifications to the surgical approach could serve as neuroprotective factors.

Strength, Limitations, and Future Perspectives

The medico-legal implications of nerve complications in hip replacement surgery are significant, given the challenges in identifying the exact cause and establishing causation. Nerve damage in these surgeries is predominantly indirect, and its precise etiology often remains unknown. Factors such as decreased muscle tone, defense mechanism impairment, and inattentiveness of operating room personnel contribute to perioperative injuries, which can occur before, during, and after surgery[6,29]. Intraoperative neurophysiological monitoring plays a crucial role in addressing these medico-legal aspects by providing real-time assessment of nerve function, aiding in the early identification of potential damage, and contributing valuable evidence to determine iatrogenic causation[30]. However, further research is needed to fully understand the underlying mechanisms and risk factors involved in nerve damage during hip replacement surgery. In conclusion, our study underscores the importance of considering medico-legal implications in nerve complications during hip replacement surgery. Intraoperative neurophysiological monitoring serves as a valuable tool for assessing causation, as it helps identify potential nerve damage and provides evidence regarding iatrogenic origin. Future research should focus on gaining a deeper understanding of the precise etiology of nerve injuries, thus improving patient outcomes and contributing to the legal framework surrounding these cases.

Conclusions

Incorporating neuromonitoring techniques to evaluate nerve function during surgery is crucial as it enables the early detection of direct nerve damage and helps mitigate the risk of severe post-surgical complications. The results of this study carry significant implications for the future management of patients with DDH type 4 undergoing total hip replacement surgery. Implementing peri-operative neuromonitoring may be imperative to safeguard against direct nerve injuries, enhance patient outcomes, and provide valuable insights for legal considerations.

Conflict of Interest
The authors declare no conflicts of interest associated with this research study.

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Informed Consent

Prior to participation in this study, all patients were provided with detailed information about the purpose, procedures, potential risks, and benefits involved. Written informed consent was obtained from each patient, ensuring their voluntary participation. The consent form outlined the nature of the study, confidentiality of data, and their right to withdraw at any time without consequences. Patients were given sufficient time to review the information, ask questions, and make an informed decision regarding their participation. The study protocol adhered to the ethical guidelines outlined by the WMA Declaration of Helsinki to ensure the protection of participants' rights and welfare.

Availability of Data and Materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request. Restrictions may apply to the availability of some materials, such as specific software or proprietary datasets, which may require separate permissions or licenses. Any additional information or materials necessary to reproduce the results or support the findings of this study can be obtained by contacting the corresponding author.

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ORCID ID

A. Taheriazam: 0000-0002-3907-925X
S. Baghbani: 0000-0002-8441-3544
M. Malakooti: 0000-0002-8176-0436
F. Jahanshahi: 0000-0002-1941-7370
M. Allahyari: 0009-0005-8369-9519
A. Dindar Mehrabani: 0000-0001-6122-7266
S. Amiri: 0000-0003-0433-0798.

Authors' Contributions

Each author made significant contributions to this study. A. Taheriazam, F. Jahanshahi, and M. Malakooti contributed to the conception and design of the research, data collection, analysis, and interpretation of the results. M. Malakooti, F. Jahanshahi, S. Amiri, and S. Baghbani contributed to the surgical procedures and data collection. M. Allahyari, A. Dindar Mehrabani, and S. Amiri provided expertise in the statistical analysis and interpretation of the data. M. Malakooti and F. Jahanshahi contributed to the literature review and manuscript writing. All authors critically reviewed and approved the final version of the manuscript.
In addition, all authors have agreed to take responsibility for the accuracy and integrity of the work as a whole.

Ethics Approval

This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki. The research protocol and procedures were reviewed and approved by the ethical committee of Azad University of Medical Sciences (Ethical approval code: IR.IAU.TMU.REC.1401.025, issued on April 22, 2022). Confidentiality of participant data was strictly maintained, and all data were anonymized and stored securely. The study was conducted with the utmost consideration for the rights, safety, and well-being of the participants.

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