Anesthetic, Patient, and Surgical Risk Factors for Neurologic Complications After Prolonged Total Tourniquet Time During Total Knee Arthroplasty

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Nerve injury after prolonged tourniquet inflation results from the combined effects of ischemia and mechanical trauma. Tourniquet release, allowing a reperfusion interval of 10–30 min followed by re-inflation, has been recommended to extend the duration of total tourniquet time. However, this practice has not been confirmed clinically. We retrospectively reviewed the medical records of 1001 patients undergoing 1166 primary or revision knee replacements with tourniquet time more than 120 min during a 5-yr interval. Mean total tourniquet time was 145 ± 25 min (range, 120–308 min). In 759 patients, the tourniquet inflation was uninterrupted. Two tourniquet inflations, interrupted by a single deflation, were noted in 371 patients, and 3 tourniquet inflations interrupted by 2 deflation intervals were noted in 23 patients. A total of 129 neurologic complications (peroneal and/or tibial nerve palsies) were noted in 90 patients for an overall incidence of 7.7%. Eighty-five cases involved the peroneal nerve and 44 cases involved the tibial nerve. In 39 cases, both peroneal and tibial deficits were noted. Complete neurologic recovery occurred in 76 (89%) peroneal and 44 (100%) tibial palsies. Postoperative neurologic dysfunction was associated with younger age ($P < 0.001$; odds ratio = 0.7 per 10-yr increase), longer tourniquet time ($P < 0.001$; odds ratio = 2.8 per 30-min increase), and preoperative flexion contracture >20° ($P = 0.002$; odds ratio = 3.9). In a subset of 116 patients with tourniquet times ≥180 min, longer duration of deflation was associated with a decreased frequency of neurologic complications ($P = 0.048$). We conclude that the likelihood of neurologic dysfunction increases with total tourniquet time and that a reperfusion interval only modestly decreases the risk of nerve injury.

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Nerve injury after prolonged tourniquet inflation results from the combined effects of ischemia and mechanical trauma. Although the safe duration of tourniquet inflation remains controversial, previous investigators have advocated time limits ranging from 1 h to 3 h (1). Tourniquet release, allowing a reperfusion interval of 10–30 min followed by reinflation, has been recommended to extend the duration of total tourniquet time (2). However, the efficacy of a reperfusion interval in reducing neural ischemia has not been confirmed in human studies. Although severe nerve injury after tourniquet use is rare (1), the effects of tourniquet inflation may be enhanced by surgical stretch or trauma: the neural "double-crush," which hypothesizes that nerve fibers already compromised are more vulnerable to injury at another site (3–5).

Peroneal palsy is a recognized complication of total knee arthroplasty (TKA), occurring in 0.3% to 10% of cases (4–8). Several patient variables, including valgus or contracture deformities, have been associated with an increased risk for the development of peroneal palsy through increased nerve traction at the surgical site perioperatively. Likewise, multiple studies have suggested that the presence of a preexisting neuropathic condition or prolonged total tourniquet time further increase the risk of peroneal nerve dysfunction (4,5). Applying the double-crush scenario, prolonged tourniquet ischemia (to both the tibial and peroneal components of the sciatic nerve at thigh level) in association with surgical traction (to the peroneal nerve at the fibular head) increases the likelihood of clinically significant neural dysfunction. Postoperatively, the presence of epidural analgesia has been reported

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to increase the frequency (5) and/or severity (4) of peroneal nerve palsy, although the mechanism is unknown. Thus, neurologic function is dependent on multiple variables, many of which may be influenced by surgical and anesthetic management.

This study evaluated a patient population with a significant risk of neurologic complications to identify contributing patient, anesthetic, and surgical risk factors. Identification of risk factors may theoretically improve patient care by allowing optimization of surgical and anesthetic management to avoid nerve injury, as well as early diagnosis and intervention to improve neurologic recovery.

Methods

After approval of our IRB, the medical records of all patients undergoing TKA between 1993 and 1998 with tourniquet times longer than 120 min were retrospectively reviewed. Demographic data, systolic blood pressure, the presence of a preexisting central or peripheral neurologic condition, or a diagnosis of diabetes requiring treatment with oral drugs or insulin were noted. Preoperative surgical diagnosis (degenerative joint disease, rheumatoid arthritis), a history of tibial osteotomy, the presence of preoperative valgus and contracture deformities, surgical procedure (primary, revision; unilateral, bilateral), and surgical time were recorded. Tourniquet inflation pressure, total tourniquet time, and reperfusion intervals were noted. A reperfusion interval was defined as ≥5 min of tourniquet deflation. Intraoperative anesthetic technique and the presence/duration of epidural analgesia were reported. Excessive postoperative bleeding (increased drainage from the surgical site, wound hematoma) was noted.

Neurologic examination was performed and documented in the hospital record before discharge from the recovery room, immediately on arrival to the hospital ward, every 4 h on the operative day by nursing staff, and a minimum of twice daily by both nursing staff and the surgical service. Patients with postoperative neurologic dysfunction were identified. The date of diagnosis and degree of sensory/motor deficits were recorded. Motor deficits were defined as complete (no motor response) or partial (incomplete/weak motor responses), whereas sensory loss was defined as complete (no sensation) or partial (less than complete sensory loss). Therapeutic measures to reduce further neural damage, such as loosening of constrictive dressings, or placement of the leg in flexion were noted. The clinical course of patients with postoperative neurodeficits and degree of neurologic recovery were recorded. Recovery was defined as none, partial, or complete.

Data are summarized using mean ± SD for continuous variable and percentages for categorical variables. For individuals who underwent multiple procedures with total tourniquet time >120 min, patient and procedural characteristics were recorded separately for each knee replacement procedure, and for analysis purposes all procedures were assumed to be independent. Logistic regression was used to identify characteristics associated with postoperative neurologic dysfunction. In addition to univariate analyses, multiple logistic regression was used to identify a set of independent predictors of postoperative neurologic dysfunction. Because of the large number of potential predictors evaluated, statistical analyses were performed using $P \leq 0.01$ to denote statistical significant to reduce the likelihood of type I error. All analyses were performed using the SAS® statistical software package (version 8; SAS® Institute, Cary, NC).

Results

During the study period there were 1001 individuals who underwent a total of 1166 primary or revision knee replacements with tourniquet time ≥120 min, including 155 individuals who underwent 2 procedures and 5 individuals who underwent 3 procedures. Mean patient age at the time of the procedure was 67 ± 11 yr (range, 16–89 yr). A preexisting neurologic condition at the time of the procedure was noted in 208 (18%) patients, including 40 instances in which the patient had multiple neurologic diagnoses. The study includes 820 (70%) procedures that were unilateral knee replacements and 346 (30%) procedures that were performed as part of a bilateral knee replacement. In the case of bilateral surgery, each joint was considered a separate procedure and only those with tourniquet time >120 min are included in the study. Surgery was performed under neuraxial or general anesthesia with similar frequency. An epidural catheter remained indwelling postoperatively in 28 (2%) procedures for a median duration of 1.6 days (range, 0.3 to 3.0 days). The epidural solution contained a local anesthetic (bupivacaine 0.1% to 0.25%) in 14 procedures.

Mean total tourniquet time was 145 ± 25 min (range, 120–308 min). For 759 (65%) procedures, the tourniquet inflation was uninterrupted and the inflation interval was 135 ± 14 min (range, 120–216 min). Two tourniquet inflations, interrupted by a single deflation, were noted in 371 (32%) procedures; and 3 tourniquet inflations interrupted by 2 deflation intervals were noted in 23 (2%) procedures. In 13 patients, the total tourniquet time was reported, but the use of a deflation interval was not specified. In procedures with 2 inflations, the total tourniquet time was 163 ± 30 min (range, 120 to 308 min) and the duration of the

Table 1. Peroneal and Tibial Palsy Characteristics

	Peroneal palsy (n = 85)	Tibial palsy (n = 44)
Sensory deficit		
Partial	71 (84)	41 (93)
Complete	5 (6)	1 (2)
Motor deficit		
Partial	34 (40)	8 (18)
Complete	5 (6)	1 (2)
Duration of palsy		
≤1 day	36 (42)	25 (57)
2–3 days	22 (26)	10 (23)
4–5 days	10 (12)	6 (14)
≥6 days	17 (20)	3 (7)
Recovery of palsy		
None	2 (2)	0 (0)
Partial	7 (8)	0 (0)
Complete	76 (89)	44 (100)

Values are n (%).

Peroneal and/or tibial palsy was observed in 90 (7.7%) of 1166 procedures. Of the 90 procedures with a postoperative palsy, 46 involved the peroneal nerve only, 5 involved the tibial nerve only, and 39 involved both peroneal and tibial nerves. More than one deficit (sensory versus motor) may have been present for each procedure.

first and second inflation intervals were 112 ± 28 min (range, 5 to 186 min) and 51 ± 26 min (range, 6 to 163 min), respectively. In procedures with 3 inflations, the total tourniquet time was 184 ± 38 min (range, 125 to 257 min), with interval durations of 93 ± 31 min (range, 5 to 136 min), 46 ± 31 min (range, 6 to 116 min), and 45 ± 23 min (range, 11 to 120 min), respectively. For all procedures, the longest uninterrupted tourniquet time without deflation was 128 ± 19 min (range, 59 to 216 min). For the procedures with at least 1 tourniquet deflation the mean duration of any deflation was 32 ± 29 min (range, 6 to 202 min); 145 (13%) procedures had at least 1 deflation interval that was ≥30 min in duration. The tourniquet inflation pressure was 300 mm Hg in 92% of procedures.

A total of 129 neurologic complications (peroneal and/or tibial nerve palsies) were noted in 90 procedures for an overall incidence of 7.7%. Eighty-five cases involved the peroneal nerve, while 44 cases involved the tibial nerve (Table 1). In 39 cases, both peroneal and tibial deficits were noted in the same limb. There were also six patients, all undergoing bilateral knee replacement, who developed bilateral peroneal palsies. The majority of neuropraxias were partial palsies; few cases involved complete sensory or motor deficits. In three patients with bilateral peroneal palsies, bilateral tibial dysfunction was also noted (Table 2).

Neurologic dysfunction was reported 26 ± 91 h after surgical closure; 86% of palsies were diagnosed within 24 h postoperatively. On detection of neurologic dysfunction, one or more interventions were initiated in 32 (36%) cases including loosening the dressings (16 cases) and placing the knee in flexion (9 cases). In 48% of cases with motor deficits an intervention was performed, whereas only 26% of cases with sensory deficits underwent an intervention to reduce neural stretch or compression (P = 0.036). Return of neurologic function was relatively rapid, with 68 (80%) peroneal palsies and 41 (93%) tibial palsies recovering completely before hospital dismissal. Recovery often continued after discharge. Complete neurologic recovery occurred in 76 (89%) peroneal palsies and 44 (100%) tibial palsies. Overall, sensory deficits were more likely to recover completely than motor deficits ($P < 0.001$). Likewise, compared with tibial dysfunction, peroneal dysfunction was more common ($P < 0.001$) and more severe ($P < 0.001$), with recovery less complete ($P < 0.035$).

Patient and procedural characteristics evaluated as potential predictors of postoperative neurological complications are summarized in Tables 3 and 4. From univariate analysis, the likelihood of neurological complications increased with younger age ($P < 0.001$), lower preoperative systolic blood pressure ($P = 0.008$), preoperative flexion contracture >20° ($P < 0.001$), revision and bilateral procedures ($P = 0.005$), longer surgical duration ($P < 0.001$), longer total tourniquet time ($P < 0.001$), longer uninterrupted tourniquet inflation without deflation ($P = 0.001$), and use of tourniquet deflation ($P < 0.001$). Although not statistically significant, there was some evidence suggesting that neurological complications were univariately associated with previous upper tibial osteotomy ($P = 0.047$), use of general anesthesia ($P = 0.038$), use of postoperative epidural analgesia ($P = 0.050$), and the occurrence of bleeding complications ($P = 0.027$). From multivariate analysis, postoperative neurologic dysfunction was found to be associated with younger age ($P < 0.001$; odds ratio = 0.7 per 10-yr increase), longer tourniquet time ($P < 0.001$; odds ratio = 2.8 per 30-minute increase) and preoperative flexion contracture >20° ($P = 0.002$; odds ratio = 3.9) (Table 5).

As noted by univariate analysis, procedures performed without interim tourniquet deflation were found to have less neurologic complications (4%) compared with those interrupted by one or more deflation intervals (complication frequency of 13%, 17%, and 12% for deflation intervals of 5–14, 15–29, and ≥30 min duration, respectively). However, because interim deflation was more likely to occur during procedures with longer tourniquet time, a separate analysis was performed to assess the association between duration of tourniquet deflation and frequency of neurologic complication in the subset of 116 procedures with total tourniquet time ≥180 min. For these 116 procedures, neurologic complications were observed in 6 of 14 (43%) with no interim deflation, 8 of 19 (42%) with a deflation lasting 5 to 14 min in duration, 16 of 42 (38%) with a deflation interval of 15 to 29 min, and 9 of 41 (22%) with a deflation interval of ≥30 min. From

Table 2. Profile of Patients with Bilateral Peroneal Palsy after Bilateral Total Knee Replacement

Gender/ age (yr)	Systolic blood pressure (mm Hg)	Preexisting neuropathy	Anesthetic	Total tourniquet time (min)	Concomitant tibial involvement	Palsy characteristics	Duration	Recovery
M/46	130	None	Spinal	R-215 L-110*	Yes-bilaterally	Partial sensory	<24 h	Complete
M/81	145	Previous laminectomy	General	R-108* L-147	Yes-bilaterally	Partial sensory	<24 h	Complete
F/62	138	None	General	R-185 L-189	Yes-bilaterally	Partial sensory	<24 h	Complete
M/66	110	Spinal stenosis	General	R-128 L-190	No	Partial motor	<24 h	Complete
73/M	150	Peripheral neuropathy	Epidural	R-129 L-98*	No	Partial sensory and motor	R-present at 12 d L <48 h	R-partial L-complete
M/65	144	None	General	R-143 L-115*	No	Partial sensory	<48 h	Complete

The surgical indication was degenerative joint disease in all patients. No patient had a flexion contracture >20 degrees or received epidural analgesia.
* These procedures were performed with total tourniquet times <120 min and were not included in the 1166 procedures that comprise the study sample.

logistic regression analysis, there was some evidence ($P = 0.048$) indicating that longer duration of deflation was associated with a decreased frequency of neurologic complications for this subset of procedures.

Discussion

Significant and persistent neurologic dysfunction is a rare complication of tourniquet application. Previous studies have estimated the overall frequency to range from 0.01%–0.13% (9,10). However, clinical investigations have demonstrated that a significantly larger percentage of patients may have abnormal postoperative electromyographic findings consistent with either subclinical or unrecognized neurologic symptoms (11–13). In a group of 24 patients undergoing outpatient knee arthroscopy using a tourniquet (inflation time, 42 ± 10 minutes; range, 8–90 minutes), 17 (71%) patients had electromyographic evidence of denervation 6 weeks postoperatively (12). These abnormalities persisted for 3 to 6 months and were associated with functional weakness of the lower extremity and prolonged recovery times. Although the pathophysiology of nerve injury associated with tourniquet use remains unclear, it is likely that both mechanical compression and neural ischemia play an important role. This theory is supported by the asymmetric pattern of nerve injury, where the greatest disruption in neural structural and function occur immediately beneath the tourniquet (14).

Our study evaluated the combined effects of lower extremity tourniquet inflation and surgery on the frequency and severity of neurologic complications. Most series have reported the frequency of peroneal palsy after TKA to be <3%, whereas tibial palsy was relatively rare (4,6–8). We reported relatively high frequencies of peroneal (7.2%) *and* tibial (3.8%) neurologic dysfunction postoperatively. However, a known risk factor, total tourniquet time longer than 120 minutes, was present in all patients in our series (1,4). Compression and ischemia of the entire sciatic nerve at the level of the thigh during prolonged tourniquet inflation will increase the probability of not only peroneal but also tibial involvement. However, because the tibial component is not traumatized surgically, the dysfunction should be less compared with the peroneal component. This is supported by our results, which note that tibial involvement occurred less frequently, was less severe, and was more likely to recover compared with peroneal neuropraxia.

Laboratory and clinical investigations have consistently demonstrated the deleterious effects of increased tourniquet duration and inflation pressure on the frequency and severity of neuropraxia (1,11,15). Importantly, nerve function may be compromised by tourniquet inflation at pressures and durations used clinically (1,16,17). Although previous studies have noted that tourniquet times beyond 2 hours were associated with an increased risk of clinically significant tourniquet compression (1), our investigation was the first to evaluate the effect of tourniquet inflation time as a continuum and quantify the risk. We reported a strong correlation of nerve injury with prolonging total tourniquet time, with an approximate threefold increase in risk of neurologic complications for each 30-minute increase in tourniquet inflation. The duration of uninterrupted tourniquet inflation also increased the likelihood of neural dysfunction. In addition, because the effects of pressure and duration are additive (17), the use of the lowest effective inflation pressure has been advocated to minimize tourniquet-related nerve injury (18). We were unable to evaluate the tourniquet inflation pressure directly as a risk factor, as this variable was not reported for all patients. However, we noted an increase in postoperative neurologic dysfunction with

Table 3. Patient Characteristics Potentially Associated with Peroneal or Tibial Palsy

Characteristic	N*	Palsy *n* (%)	*P* value†
Age (yr)			<0.001
≤64	361	45 (12)	
65–75	570	30 (5)	
≥76	235	15 (6)	
Gender			0.946
Male	587	45 (8)	
Female	579	45 (8)	
Preoperative systolic blood pressure (mm Hg)			0.008
≤134	441	42 (10)	
135–150	413	28 (7)	
≥151	335	20 (6)	
Diabetes			0.700
No	1035	81 (8)	
Yes	131	9 (7)	
Any preexisting neurological condition			0.376
No	955	70 (7)	
Yes	208	19 (9)	
Previous upper tibial osteotomy			0.047
No	1094	80 (7)	
Yes	72	10 (14)	
Surgical indication			0.152
Degenerative joint disease	1018	74 (7)	
Rheumatoid arthritis	75	6 (8)	
Other	64	9 (14)	
Preoperative valgus, degrees			0.999
0	818	63 (8)	
1–9	219	17 (8)	
≥10	129	10 (8)	
Preoperative flexion contracture, degrees			<0.001
0–20	1124	80 (7)	
>20	42	10 (24)	

* During the study period there were 1001 individuals who underwent a total of 1166 primary or revision knee replacement procedures with tourniquet time ≥120 min. For individuals who underwent multiple procedures, patient and procedural characteristics were recorded separately for each knee replacement procedure, and for analysis purposes all procedures were assumed to be independent. As a result of missing data the number of patients across categories of a given characteristic does not always sum to 1166.

† Univariate analysis was performed using logistic regression. For the logistic regression models, age and preoperative arterial blood pressure were treated as continuous variables and all other characteristics were treated as classification variables.

Table 4. Procedural Characteristics Potentially Associated with Peroneal or Tibial Palsy

Characteristic	N*	Palsy *n* (%)	*P* value†
Surgical procedure			0.005
Unilateral primary arthroplasty	517	26 (5)	
Unilateral revision arthroplasty	303	34 (11)	
Bilateral primary or revision arthroplasty	341	30 (9)	
Surgical duration (min)			<0.001
≤179	232	4 (2)	
180–209	340	13 (4)	
210–239	224	17 (8)	
≥240	369	56 (15)	
Total tourniquet time (min)			<0.001
120–134	509	12 (2)	
135–149	319	13 (4)	
150–179	222	26 (12)	
≥180	116	39 (34)	
Longest tourniquet interval without deflation (min)			0.001
120–134	763	47 (6)	
135–149	286	21 (7)	
150–179	74	8 (11)	
≥180	30	13 (43)	
Duration of deflation (min)‡			<0.001
No Deflation	759	34 (4)	
5–14	93	12 (13)	
15–29	156	26 (17)	
≥30	145	17 (12)	
Anesthetic technique			0.038
Neuraxial	623	38 (6)	
General	522	49 (9)	
Combined**	21	3 (14)	
Postoperative epidural analgesia			0.050
No	1138	85 (7)	
Yes	28	5 (18)	
Any bleeding complication			0.027
No	1124	83 (7)	
Yes	41	7 (17)	

* During the study period there were 1001 individuals who underwent a total of 1166 primary or revision knee replacement procedures with tourniquet time ≥120 min. For individuals who underwent multiple procedures, patient and procedural characteristics were recorded separately for each knee replacement procedure, and for analysis purposes all procedures were assumed to be independent. As a result of missing data the number of patients across categories of a given characteristic does not always sum to 1166.

† Univariate analysis was performed using logistic regression. For the logistic regression models, duration of surgery, total tourniquet time, and longest tourniquet inflation without deflation were treated as continuous variables and all other characteristics were treated as classification variables.

‡ There were 759 procedures that did not have tourniquet deflation, 371 that had a single deflation, and 23 patients who had 2 deflations. For procedures that had 2 deflations, the duration of deflation was defined as the maximum of the 2 deflation intervals.

** This group was not included in the analysis.

younger age (odds ratio of 0.7 per 10-year increase). This association likely reflects the relationship between age and systolic blood pressure because the difference between tourniquet inflation pressure (which was 300 mm Hg in 92% of patients) and systolic blood pressure would be larger in young patients and more likely to lead to excessive compression and ischemia.

Deflating the tourniquet to allow a period of reperfusion has been advocated to minimize the effects of skeletal muscle injury when extended tourniquet inflation time (longer than 2 hours) is anticipated (1,2). However, the efficacy of tourniquet deflation/release (reperfusion interval) in decreasing ischemic injury to nerve remains largely unstudied. A single laboratory investigation in rabbits concluded that a 4-hour interval of tourniquet ischemia interrupted by a single 10-minute reperfusion interval at 2 hours, or by 10 minutes of reperfusion after each hour, failed to diminish the neurologic injury (18). Importantly, no previous clinical study evaluated the

Table 5. Multivariate Analysis of Characteristics Associated with Peroneal or Tibial Palsy*

Characteristic	Odds ratio†	95% confidence interval	*P* value
Age (yr)†	0.7	0.6 to 0.8	<0.001
Preoperative flexion contracture >20	3.9	1.6 to 9.1	0.002
Total tourniquet time (min)†	2.8	2.3 to 3.5	<0.001

* Multiple logistic regression analysis was performed using backward elimination of nonsignificant variables with all patient and procedural characteristics from Table 3 and Table 4 included in the initial step. The odds ratios and corresponding 95% confidence intervals are provided for the characteristics included in the final model.

† Age and total tourniquet time were treated as continuous variables in the logistic regression analysis. For age, the odds ratio provided is for a 10-yr increase and for total tourniquet time the odds ratio provided is for a 30-min increase.

effectiveness of intermittent tourniquet release in preventing neural ischemia. We noted that the effects of tourniquet inflation were only somewhat attenuated by tourniquet deflation and were most apparent with reperfusion intervals longer than those previously tested in animals, 30 minutes versus 10 minutes, respectively (18).

The majority of palsies were diagnosed within 24 hours after surgical closure, suggesting that the injury occurred during the procedure and was not the result of postoperative positioning or stretch. On diagnosis of a peroneal or tibial palsy, the recommended treatment is to remove constrictive dressings and place the knee in a flexed position to decrease traction on the sciatic nerve and its components. However, these interventions were performed in only one third of patients, typically those with complete sensory or motor deficits. It is also reassuring to note that return of neurologic function was rapid and complete, particularly in patients with sensory palsies. Conversely, the poor return of function in patients with motor deficits warrants prompt action to reduce neural pressure and traction to optimize neural recovery (6,7).

Previous studies have suggested the frequency (5) or severity (4) of peroneal palsy may be increased in patients receiving epidural analgesia. Although speculative, this was presumed to be attributable to the local anesthetic effects masking the sensory and/or motor deficits, leading to a delay in the diagnosis and intervention. As a result of these investigations, epidural analgesia has not been commonly performed after TKA in our institution. In the current series, 8 of 28 of patients who received this method of pain relief developed neurologic dysfunction ($P = 0.050$, univariate; P = not significant, multivariate). However, it is unlikely that our sample size was adequately powered to definitively evaluate epidural analgesia as a risk factor. Although not evaluated in our series, the presence of a long-lasting sciatic block would also delay the diagnosis of tibial or peroneal dysfunction and should also theoretically be avoided in patients considered at increased risk, such as those with preoperative flexion contracture >20 degrees or a valgus deformity, as well as those in whom surgery is anticipated to be complex or prolonged (necessitating extensive tourniquet inflation time).

In summary, this study evaluated patient, anesthetic, and surgical risk factors for neurologic complications after prolonged total tourniquet time during TKA. Tibial and/or peroneal nerve dysfunction occurred in 7.7% of patients and was associated with younger age, the presence of a preoperative flexion deformity, and longer total tourniquet time. A tourniquet deflation (reperfusion) interval only modestly decreased the risk of nerve ischemia. Although patient risk factors cannot be controlled, modification of surgical and anesthetic management perioperatively for patients considered at increased risk may improve neurologic outcome.

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