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Positioning in Anesthesiology

Toward a Better Understanding of Stretch-induced Perioperative Neuropathies

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Background: **Stretch-induced neuropathy of the brachial plexus and median nerve in conventional perioperative care remains a relatively frequent and poorly understood complication. Guidelines for positioning have been formulated, although the protective effect of most recommendations remains unexamined. The similarity between the stipulated potentially dangerous positions and the components of the brachial plexus tension test (BPTT) justified the analysis of the BPTT to quantify the impact of various arm and neck positions on the peripheral nervous system.**

Methods: **Four variations of the BPTT in three different shoulder positions were performed in 25 asymptomatic male participants. The impact of arm and neck positions on the peripheral nervous system was evaluated by analyzing the maximal available range of motion, pain intensity, and type of elicited symptoms during the BPTT.**

Results: **Cervical contralateral lateral flexion, lateral rotation of the shoulder and fixation of the shoulder girdle in a neutral position in combination with shoulder abduction, and wrist extension all significantly reduced the available range of motion. Elbow extension also challenged the nervous system substantially. A cumulative impact could be observed when different components were simultaneously added, and a neutralizing effect was noted when an adjacent region allowed for unloading of the nervous system.**

Conclusions: **The experimental findings support the experientially based guidelines for positioning. Especially when simultaneously applied, submaximal joint positions easily load the nervous system, which may substantially compromise vital physiologic processes in and around the nerve. Therefore, even when the positioning of all upper limb joints is carefully considered, complete prevention of perioperative neuropathy seems almost inconceivable.**

PERIPHERAL neuropathy associated with anesthesia is a significant source of morbidity and the second most frequent cause of professional liability in anesthetic practice.[1] Unfortunately, we have a limited understanding of the relations between conventional perioperative care and the genesis of peripheral neuropathy.[2]

The second most frequent site of upper extremity neuropathy, after the ulnar nerve, is the brachial plexus, followed by the median nerve.[1] Lesions at these latter two sites are often regarded as stretch-induced neuropathies.[3,4] Several positions of the upper quadrant (arm and neck) that elongate the length of the nerve bedding of the brachial plexus and median nerve have been associated with perioperative neuropathies, such as shoulder girdle depression, abduction greater than 90°, lateral rotation of the arm, lateral flexion of the patient's head to the opposite side, full elbow extension, and forearm supination.[4–6] Empirically based recommendations to restrain these positions were formulated to decrease the frequency and severity of neural complications,[5,7–10] although the protective value of these recommendations has not been assessed.

Interestingly, all of these mentioned maneuvers are part of the brachial plexus tension test (BPTT).[11] This clinical test is the equivalent of the straight leg raising test for the upper quadrant, and the test is gaining interest in manual medicine to assess increased neural mechanosensitivity in patients with peripheral neurogenic pain originating from the brachial plexus or median nerve.[12] Compliance of the brachial plexus and median nerve to elongation is assessed by a sequence of passive maneuvers. First, the arm is abducted while the shoulder girdle is held in its neutral position. Consequently, the wrist is extended, the forearm is supinated, and the shoulder is laterally rotated before terminal elbow extension is performed.[11,13] Cervical contralateral lateral flexion can be added to further increase the mechanical loading of the nervous system. The available range of elbow extension and the reproduction of the patient's symptoms are important criteria for the interpretation of the test and represent the extensibility and mechanosensitivity of the nervous system.[14]

Considering the high correlation between the different components of the BPTT and the empirically ascertained perilous positions of the arm and neck during anesthetic practice, the purpose of this study is to quantify the impact of different components of the BPTT on the upper quadrant nervous system to obtain better insight into potentially dangerous positions during anesthesia.

◇ This article is featured in "This Month in Anesthesiology." Please see this issue of ANESTHESIOLOGY, page 5A.

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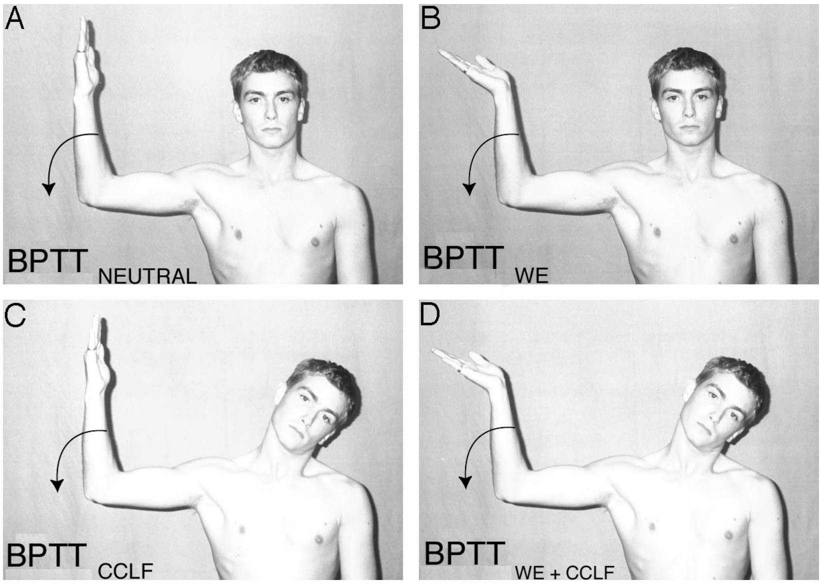

Fig. 1. Illustration of the four variations of the brachial plexus tension test (BPTT): elbow extension was performed (*A*) with the wrist and cervical spine in a neutral position ($BPTT_{NEUTRAL}$), (*B*) with wrist extension ($BPTT_{WE}$), (*C*) with cervical contralateral lateral flexion ($BPTT_{CCLF}$), and (*D*) with wrist extension and cervical contralateral lateral flexion ($BPTT_{WE + CCLF}$). The amount of wrist extension was defined as the maximal passive range minus 10°. Cervical contralateral lateral flexion was defined as the maximal passive range without provoking any sensory response. The starting position of all variations was pain- and symptom-free. The tests were stopped when submaximal discomfort was elicited or when full range of elbow extension was reached.

Materials and Methods

Subjects

Twenty-five men with no history of cervicobrachial pain or orthopedic injuries volunteered to participate (mean height: 1.82 ± 0.06 m, weight: 76.2 ± 10.8 kg, and body mass index: 23.0 ± 2.9). Their age varied from 20 to 32 (23.4 ± 3.5) yr. To be suitable for inclusion, each subject had to have pain-free, full range of motion (ROM) of the cervical spine and all individual upper limb joints. Participants were excluded from the study if the combined shoulder position of abduction and lateral rotation was limited or painful. The subjects' mean range of elbow extension was 183.4 ± 1.9°. Subjects who were aware of having diseases associated with a relatively high probability of neuropathy, such as diabetes or renal disease, were also excluded from the study. The participants signed an informed consent form, and the study was approved by the Ethical Committee for Rehabilitation Studies, University of Leuven (Leuven, Belgium).

Test Description

To obtain better insight into the potentially hazardous positions, four variations of the BPTT were performed: elbow extension was performed (1) with the wrist and cervical spine in a neutral position ($BPTT_{NEUTRAL}$), (2) with wrist extension ($BPTT_{WE}$), (3) with cervical contralateral lateral flexion ($BPTT_{CCLF}$), and (4) with wrist extension and cervical contralateral lateral flexion ($BPTT_{WE + CCLF}$) (fig. 1).

These four variations were performed in three different shoulder positions: (1) with abduction and lateral rotation of the arm while the shoulder girdle was fixed in its neutral position (original BPTT[11,13]), (2) with abduction of the arm and fixation of the shoulder girdle, and (3) with abduction only (fig. 2). Because positioning in lateral rotation is not routinely performed in anesthetic practice, rotation was left out of the second and third shoulder positions. The tests were performed with and without fixation of the shoulder girdle to simulate the presence and absence of a shoulder brace.

The principal measure during the tests was the available range of elbow extension. Elbow extension was stopped when the participant reported that the test caused substantial discomfort or when full range of elbow extension was reached. Substantial discomfort was defined before the start of the experiment as the maximal tolerance level for the test, knowing that the test had to be performed repeatedly. The available range of elbow extension at this point was considered to correspond with the submaximal extensibility of the nervous system and was used for further analysis.

Experimental Setup and Procedure

Figure 2 shows the experimental setup. The range of elbow extension was measured using an electrogoniometer (M180; Penny & Giles Biometrics Ltd., Blackwood Gwent, United Kingdom). To increase accuracy, the goniometer was calibrated separately for the tests with and without lateral rotation. The pain intensity elicited at the end of the test was measured using a numeric pain intensity rating scale, ranging from 0 (no pain) to 10 (worst pain possible). The types of elicited symptoms were recorded on a body chart. A load cell (535QD; DS Europe, Milan, Italy) was used to standardize the amount of depression force to reposition the shoulder girdle toward its neutral position and to block the shoulder girdle in this position. The load cell was positioned over the acromioclavicular joint, the advocated location for shoulder braces.[15]

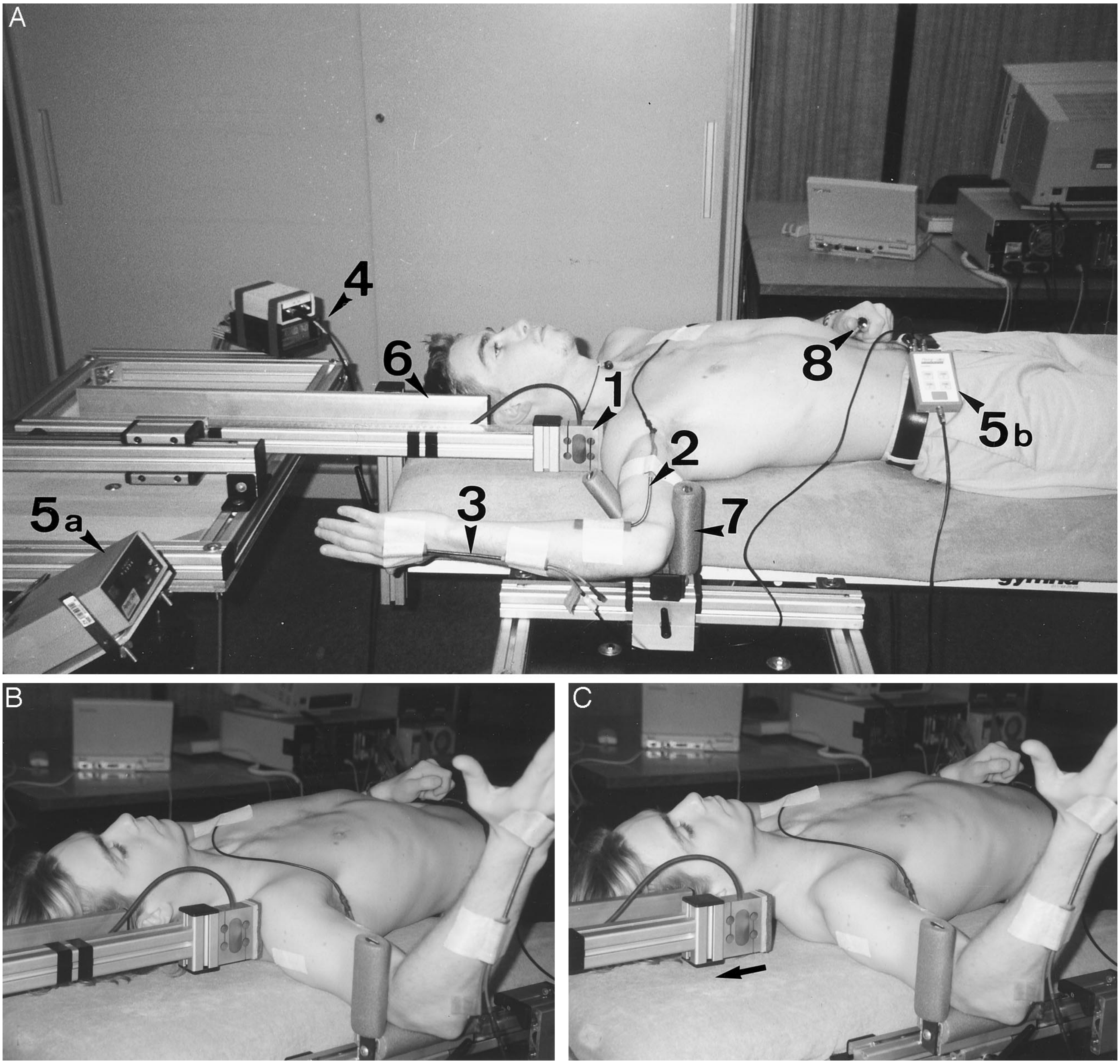

Fig. 2. The experimental setup, showing the subject in the three shoulder positions. (*A*) The original brachial plexus tension test position with the shoulder in 90° abduction and 90° lateral rotation; the shoulder girdle is repositioned to its neutral position by a gentle depression force of 30 N. The figure shows the load cell (1); the electrogoniometer of the elbow (2) and of the wrist (3); the amplifier and digital display of the load cell (4); the K100 amplifier of the electrogoniometers, including a base unit with LCD display (5a) and a patient unit (5b); the head restraint (6); the arm rest (7); and a handheld switch (8, not used in this study). (*B*) The shoulder positioned in 90° abduction, no lateral rotation, but with fixation of the shoulder girdle in a neutral position. (*C*) The shoulder positioned in abduction, no lateral rotation and no fixation of the shoulder girdle.

The order of the four test variations was randomized to counterbalance possible effects of repeated testing. This sequence was repeated in the three different shoulder positions, which were also performed in different order. Two trial runs were performed to familiarize the subject with the procedure. To allow calculation of the reliability of the available range of elbow extension, three repetitions were performed by a first tester, followed by one repetition of a second tester. Throughout the experiment, the tester was blinded to the output of the electrogoniometer. A custom-made software program was used for data acquisition. A detailed description of the experimental devices and methodology has been reported elsewhere.[16]

Statistical Analysis

Intraclass correlation coefficients (ICCs) were calculated as a measure of reliability for the available ROM (ICC[2,1] and ICC[2,3]).[17] Intratester reliability was assessed by analyzing the three repetitions of the first tester; intertester reliability was assessed by comparing

Table 1. Mean Range of Elbow Extension (SD; Range [Minimum–Maximum]) for the Four Variations in the Three Shoulder Positions

Shoulder Position		$BPTT_{NEUTRAL}$	$BPTT_{WE}$	$BPTT_{CCLF}$	$BPTT_{WE + CCLF}$
Abduction No lateral rotation No fixation	(C)	184.1 (4.5; 173.6–190.9)	180.6 (6.7; 162.7–188.5)	184.7 (5.0; 171.9–192.0)	180.2 (6.7; 163.4–192.1)
	↑ S ↓	↑ S ↓	↑ S ↓	↑ S ↓	↑ S ↓
Abduction No lateral rotation Fixation in a neutral position	(B)	179.0 (6.0; 163.3–191.0)	172.1 (10.4; 146.1–184.6)	174.7 (9.5; 145.7–188.4)	163.7 (13.4; 135.0–181.3)
	↑ NS ↓	↑ NS ↓	↑ NS ↓	↑ S ↓	↑ S ↓
Abduction Lateral rotation Fixation in a neutral position	(A)	177.6 (8.1; 153.3–189.3)	168.3 (13.0; 136.9–184.9)	159.5 (14.2; 125.0–181.6)	144.3 (12.6; 125.2–177.5)

Results of the multiple comparison analysis (Tukey HSD) have been added: S = significant ($P < 0.05$); NS = non significant.

BPTT = brachial plexus tension test; NEUTRAL = wrist and cervical spine in a neutral position; WE = wrist extension; CCLF = cervical contralateral lateral flexion. A, B, and C correspond with the shoulder positions shown in figure 2.

the first repetition of the first tester with the repetition of the second tester. In addition, the standard errors of measurement were calculated as a function of the pooled group SD and the reliability coefficient.[18]

Results are presented as mean amplitudes (± SD; range [minimum–maximum]). Two-way analysis of variance, with two repeated factors (shoulder position × variations), in combination with Tukey HSD *post hoc* multiple comparison tests, was used to analyze differences in range of elbow extension. The number of levels coded under the shoulder position and variations factors were three and four, respectively. One-way analysis of variance, repeated-measures design, was used to analyze differences in pain intensity among the four different variations in the original BPTT position. The level of significance chosen was $P < 0.05$.

Results

From a statistical as well as from a clinical point of view, the reliability of measurement of the available ROM was excellent. The mean intratester reliability among the 12 tests was 0.96, with a mean standard error of measurement of 1.8°. When three repetitions were used as the unit of analysis, the mean reliability increased to 0.99, with a mean standard error of measurement of 1.0°. The mean intertester reliability among the 12 tests was 0.93, with a mean standard error of measurement of 2.3°.

Table 1 summarizes the mean range of elbow extension for the four different variations in the three different shoulder positions. In general, the available ROM decreased, and the variability among subjects, represented by the standard deviations, increased when more test components were added. The results are graphically presented in figure 3.

The analysis of variance revealed a significant interaction for the ROM between the shoulder positions and test variations ($F_{6,144} = 41.5$; $P < 0.0001$). A significant main effect was present for the shoulder positions ($F_{2,48} = 90.2$; $P < 0.0001$). Additional analysis revealed significant differences in the available range of elbow extension for all three shoulder positions ($P < 0.05$). A significant main effect was also present for the test variations ($F_{3,72} = 102.8$; $P < 0.0001$). The following significant differences were found: (1) the addition of wrist extension ($BPTT_{WE}$) or cervical contralateral lateral flexion ($BPTT_{CCLF}$) resulted in a significantly reduced ROM when compared with $BPTT_{NEUTRAL}$ ($P < 0.05$); (2) the simultaneous addition of wrist extension and cervical contralateral flexion ($BPTT_{WE + CCLF}$) resulted in a significantly smaller ROM when compared with $BPTT_{WE}$ and

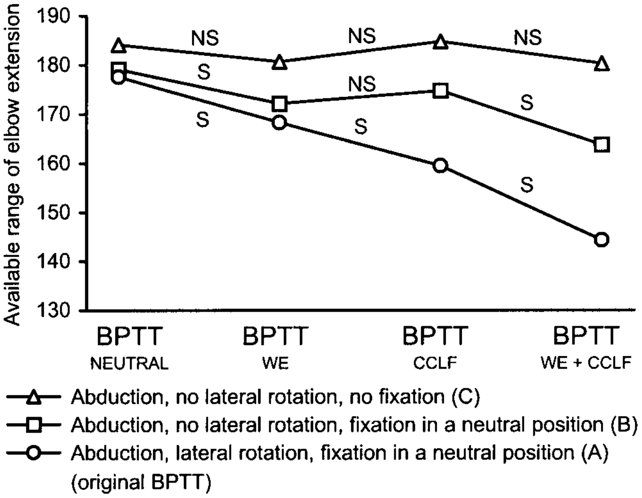

Fig. 3. The available range of elbow extension for the different tests. For each of the three shoulder positions, the four test variations were grouped. The difference between the top and middle lines shows the significant impact of shoulder girdle fixation. The difference between the middle and lowest lines shows the significant impact of lateral rotation of the shoulder. Differences in range of motion between the test variations within the same shoulder position have been labeled: S = significant ($P < 0.05$); NS = nonsignificant. BPTT = brachial plexus tension test; NEUTRAL = with the wrist and cervical spine in a neutral position; WE = wrist extension; CCLF = cervical contralateral lateral flexion (fig. 1). A, B, and C correspond with the shoulder positions shown in figure 2.

$BPTT_{CCLF}$ ($P < 0.05$); (3) no significant overall difference in ROM was observed between the addition of wrist extension ($BPTT_{WE}$) and cervical lateral flexion ($BPTT_{CCLF}$) ($P = 0.90$).

A selection of results of the multiple comparison procedure analyzing the differences among individual tests is reported. These results are given in figure 3 and table 1.

With the shoulder positioned in the original BPTT position, pain intensity increased significantly when more components were added to the test ($BPTT_{NEUTRAL}$: 4.1 ± 1.5, $BPTT_{WE}$: 5.1 ± 1.9, $BPTT_{CCLF}$: 5.7 ± 1.4, $BPTT_{WE\,+\,CCLF}$: 6.4 ± 1.3; $P < 0.05$). In addition, the number of subjects reporting paraesthesia increased when more components were added ($BPTT_{NEUTRAL}$: 12%, $BPTT_{WE}$: 36%, $BPTT_{CCLF}$: 48%, $BPTT_{WE\,+\,CCLF}$: 72%).

Discussion

The BPTT was analyzed to quantify the impact of various arm and neck positions on the upper quadrant nervous system to obtain better insight into potentially dangerous positions associated with stretch-induced neuropathies in anesthetic practice. Cervical contralateral lateral flexion, depression of the shoulder girdle and lateral rotation of the shoulder in combination with shoulder abduction, and wrist extension all had a significant effect on the available range of elbow extension. Furthermore, because all starting positions were painfree and because a substantial discomfort was elicited when the elbow was extended, it could be inferred that elbow extension also substantially challenged the nervous system. In addition, a higher pain intensity and a larger number of subjects reporting paresthesia could be observed when more test components were simultaneously applied.

The findings of this study support the experientially based recommendations regarding potentially dangerous positions.[5,7–10] Based on our findings, we suggest that the dangerous positions mentioned herein should be avoided whenever possible. Because various perioperative neuropathies have been reported when shoulder braces were used,[6,10] the impact of shoulder fixation deserves special attention, especially because one third of the members of the American Society of Anesthesiologists either do not know or disagree with the opinion that the use of shoulder braces impacts the risk of peripheral neuropathy.[7] When fixation was added, all tests resulted in a significantly reduced ROM, even when the fixation force was applied over the advocated region, *i.e.*, the acromioclavicular joint. Therefore, we strongly discourage use of shoulder braces whenever possible in patient positioning. However, if braces must be used, as for example in steep head-down tilt during laparoscopic surgery, nonsliding mattresses should be added. Furthermore, the pressure of the braces on the shoulder girdle should be controlled regularly, and if necessary, the position of the braces should be adjusted during anesthesia.

Based on the results of the different tests, the continuity of the nervous system can be regarded as the common denominator for a cumulative and neutralizing effect. The cumulative effect indicates that when different positions that individually load the nervous system are simultaneously added, their impact on the nervous system is larger than when added separately. This can be clearly observed when wrist extension and cervical contralateral lateral flexion were added in the original BPTT position (fig. 3). When the wrist, shoulder, and cervical spine were simultaneously positioned in a nerve bed-lengthening position, the mean maximal tolerable range of elbow extension corresponded with an extension deficit of no less than approximately 40°. This cumulative effect is supported by anatomic studies in which a much more pronounced excursion of the median nerve was observed when joint movements were combined.[19]

The neutralizing effect indicates that the impact of a position can be reduced if a neighboring region allows for unloading of the nervous system. For example, the impact of cervical lateral flexion, even when added simultaneously with wrist extension, decreased significantly when the shoulder was not laterally rotated or fixed in a neutral position (table 1). Although both effects are important to consider in patient positioning, extrapolation of the neutralizing effect into anesthetic practice should be made carefully. The BPTT is a dynamic test of short duration, and it is unlikely that the neutralizing effect will hold to the same extent with sustained arm positions in prolonged operations. However, if one of the mentioned hazardous positions cannot be avoided, it may be worth considering positioning the adjacent joints in an unloading position.

The large interindividual differences in reaction to elongation of the nerve bedding were another key finding of this study. Maneuvers had only a minor impact in one subject, whereas the ROM was strongly limited in another subject. Noteworthy is that the variability among subjects increased as more components were added, *i.e.*, as the nervous system was loaded to a greater extent. This shows that subjects respond differently to nerve bedding elongation. Consequently, the question arises as to whether subjects with an adverse BPTT response are more prone to development of stretched-induced perioperative neuropathy. Only a large prospective study, in which neural provocation tests are included as preanesthetic screening tests, will show the additional value of the BPTT and similar tests for other major peripheral branches, *e.g.*, the ulnar nerve.[13] If these tests are able to identify patients at risk, *e.g.*, patients with an occult neuropathy before surgery, these simple and quick screening tests could become valuable tools toward prevention, as well as for medicolegal justification. Triggering a preexisting subclinical neuropathy is considered to be a possible mechanism for development of perioperative ulnar neuropathy.[20–22]

Numerous studies[19,23–26] have shown that the different components of the BPTT cause elongation, tension, and compression of the brachial plexus and median nerve. In addition, it is well-established that not only low-grade compression[27] but also elongation of merely 10–15%[28,29] is sufficient to cause important alterations in vital physiologic processes, compromising the condition of the peripheral nerve. Changes include reduced intraneural blood flow, resulting in nerve ischemia and endoneurial edema,[30–32] suppression of axonal transport,[29,33] and changes in conduction characteristics.[28,34] These mechanical and physiologic alterations probably have an important role in the genesis of stretched-induced neuropathies and in the symptoms elicited during the BPTT. However, apart from the nervous system, many nonneural elements are also challenged during the BPTT, and the question arises as to what their contribution is in the outcome of the BPTT. There are sufficient indications in this study to assume that the more positions were simultaneously applied, the smaller the importance of nonneural elements in the test result became and that the responses were indeed predominantly neurogenic. For example, bearing in mind that the starting position was symptom-free, many of the articular and muscular structures around the cervical spine, shoulder, and wrist could not have had a direct contribution to the test response because these structures do not span the elbow joint and therefore were not challenged during the test movement of elbow extension. In addition, the subjects experienced increasing pain intensity although the loading of muscular and articular structures around the elbow decreased when more components were added to the test as the tolerance level for the test was elicited earlier in range. Preloading a continuous structure, such as the nervous system, by the addition of components to the starting position seems to be an obvious and adequate explanation. Furthermore, the increasing amount of subjects reporting paresthesia when more test components were added supports the opinion that the upper quadrant nervous system was substantially challenged during the test. Therefore, we conclude that the limitation in ROM and many of the elicited symptoms can be ascribed to the peripheral nervous system, which is unable to comply sufficiently with the elongation of its nerve bedding, even in healthy subjects.

Another important aspect to consider in patient handling and positioning is the absence of protective reflexes in the anesthetized and sedated patient. Throughout progressive stages of the BPTT, Balster and Jull[35] demonstrated increasing muscular activity as loading of the nervous system increased. It is often hypothesized that this muscular activity acts as a nociceptive-mediated withdrawal reflex to protect the nervous system from harmful elongation.[11,14,35] In the absence of this protective muscle activity, the nervous system may be subject to a larger elongation perioperatively than that which would occur in activities of daily living. Suppression of this protective mechanism may also be a consideration in the selection of short- and long-acting muscle relaxants, especially in patients at risk, such as patients with diabetes mellitus and renal or vascular disease.

Based on the findings of this study and others, we advocate the following perioperative positioning of the upper quadrant to optimally protect the peripheral nervous system in the supine position. Shoulder abduction and lateral rotation should be kept to a minimum and should never be combined with the use of shoulder braces. Ideally, the head should remain in the midline position, the arm should be kept at the side, the elbow should be gently flexed to unload the median nerve, and the forearm should be supinated to protect the ulnar nerve.[36] The wrist is best positioned in the neutral position because it does not load the nervous system and approximates the position associated with the lowest carpal tunnel pressure.[37] Shoulder braces and elbow and wrist extension should be avoided whenever possible.

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References

1. Cheney FW, Domino KB, Caplan RA, Posner KL: Nerve injury associated with anesthesia: A closed claims analysis. ANESTHESIOLOGY 1999; 90:1062–9
2. Caplan RA: Will we ever understand perioperative neuropathy? A fresh approach offers hope and insight (editorial). ANESTHESIOLOGY 1999; 91:335–6
3. Dawson DM, Krarup C: Perioperative nerve lesions. Arch Neurol 1989; 46:1355–60
4. Warner MA: Perioperative neuropathies. Mayo Clin Proc 1998; 73:567–74
5. Gagnon J, Poulin EC: Beware of the Trendelenburg position during prolonged laparoscopic procedures. Can J Surg 1993; 36:505–6
6. Romanowski L, Reich H, McGlynn F, Adelson MD, Taylor PJ: Brachial plexus neuropathies after advanced laparoscopic surgery. Fertil Steril 1993; 60:729–32
7. ASA Task Force on Prevention of Perioperative Peripheral Neuropathies: Practice advisory for the prevention of perioperative peripheral neuropathies: A report by the American Society of Anesthesiologists Task Force on Prevention of Perioperative Peripheral Neuropathies. ANESTHESIOLOGY 2000; 92:1168–82
8. Martin J: Head-down tilt, Positioning in Anesthesia and Surgery, 3rd edition. Edited by Martin JT, Warner MA. Philadelphia, Saunders, 1997, pp 95–123
9. Nakata D, Stoelting R: Positioning the extremities, Positioning in Anesthesia and Surgery. Edited by Martin J, Warner M. Philadelphia, Saunders, 1997, pp 199–222
10. Goskowicz R: Use of shoulder restraints during arm abduction and steep Trendelenburg's position (letter). ANESTHESIOLOGY 1995; 83:1377
11. Elvey RL: Physical evaluation of the peripheral nervous system in disorders of pain and dysfunction. J Hand Ther 1997; 10:122–9
12. Milidonis MK, Ritter RC, Sweeney MA, Godges JJ, Knapp J, Antonucci E: Practice analysis survey: Revalidation of advanced clinical practice in orthopaedic physical therapy. J Orthop Sports Phys Ther 1997; 25:163–70
13. Butler D: The Sensitive Nervous System. Adelaide, NOIgroup Publications, 2000, p 431
14. Quintner JL: A study of upper limb pain and paraesthesiae following neck injury in motor vehicle accidents: Assessment of the brachial plexus tension test of Elvey. Br J Rheumatol 1989; 28:528–33
15. Wilcox S, Vandam LD: Alas, poor Trendelenburg and his position! A critique of its uses and effectiveness. Anesth Analg 1988; 67:574–8
16. Coppieters MW, Stappaerts KH, Everaert DG, Staes FF: A qualitative assessment of shoulder girdle elevation during the upper limb tension test 1. Man Ther 1999; 4:33–8
17. Shrout PE, Fleiss JL: Intraclass correlations: Uses in assessing rater reliability. Psychol Bull 1979; 86:420–8

18. Baumgartner TA: Norm-referenced measurement: Reliability, Measurements Concepts in Physical Education and Exercise Science. Edited by Safrit MJ, Wood TM. Champaign, Human Kinetic Books, 1989, pp 45–72

19. Wright TW, Glowczewskie F, Wheeler D, Miller G, Cowin D: Excursion and strain of the median nerve. J Bone Joint Surg [Am] 1996; 78:1897–903

20. Alvine FG, Schurrer ME: Postoperative ulnar-nerve palsy: Are there predisposing factors? J Bone Joint Surg [Am] 1987; 69:255–9

21. Stoelting RK: Postoperative ulnar nerve palsy: Is it a preventable complication? Anesth Analg 1993; 76:7–9

22. Warner MA, Warner ME, Martin JT: Ulnar neuropathy: Incidence, outcome, and risk factors in sedated or anesthetized patients. Anesthesiology 1994; 81:1332–40

23. Kleinrensink GJ, Stoeckart R, Vleeming A, Snijders CJ, Mulder PGH: Mechanical tension in the median nerve: The effects of joint positions. Clin Biomech 1995; 10:240–4

24. McLellan DL, Swash M: Longitudinal sliding of the median nerve during movements of the upper limb. J Neurol Neurosurg Psychiatry 1976; 39:566–70

25. Wilgis EF, Murphy R: The significance of longitudinal excursion in peripheral nerves. Hand Clin 1986; 2:761–6

26. Gelberman RH, Hergenroeder PT, Hargens AR, Lundborg GN, Akeson WH: The carpal tunnel syndrome: A study of carpal canal pressures. J Bone Joint Surg [Am] 1981; 63:380–3

27. Rempel D, Dahlin L, Lundborg G: Pathophysiology of nerve compression syndromes: Response of peripheral nerves to loading. J Bone Joint Surg [Am] 1999; 81:1600–10

28. Wall EJ, Massie JB, Kwan MK, Rydevik BL, Myers RR, Garfin SR: Experimental stretch neuropathy: Changes in nerve conduction under tension. J Bone Joint Surg [Br] 1992; 74:126–9

29. Tanoue M, Yamaga M, Ide J, Takagi K: Acute stretching of peripheral nerves inhibits retrograde axonal transport. J Hand Surg [Br] 1996; 21:358–63

30. Lundborg G: Intraneural microcirculation. Orthop Clin North Am 1988; 19:1–12

31. Ogata K, Naito M: Blood flow of peripheral nerve effects of dissection, stretching and compression. J Hand Surg [Br] 1986; 11:10–4

32. Rydevik BL, Kwan MK, Myers RR, Brown RA, Triggs KJ, Woo SL, Garfin SR: An in vitro mechanical and histological study of acute stretching on rabbit tibial nerve. J Orthop Res 1990; 8:694–701

33. Koike H: The disturbance of the fast axonal transport of protein by passive stretching of an axon in Aplysia. J Physiol (Lond) 1987; 390:489–500

34. Kwan MK, Wall EJ, Massie J, Garfin SR: Strain, stress and stretch of peripheral nerve: Rabbit experiments in vitro and in vivo. Acta Orthop Scand 1992; 63:267–72

35. Balster SM, Jull GA: Upper trapezius muscle activity during the brachial plexus tension test in asymptomatic subjects. Man Ther 1997; 2:144–9

36. Prielipp RC, Morell RC, Walker FO, Santos CC, Bennett J, Butterworth J: Ulnar nerve pressure: Influence of arm position and relationship to somatosensory evoked potentials. Anesthesiology 1999; 91:345–54

37. Weiss ND, Gordon L, Bloom T, So Y, Rempel DM: Position of the wrist associated with the lowest carpal-tunnel pressure: Implications for splint design. J Bone Joint Surg [Am] 1995; 77:1695–9