Carpal tunnel pressure measurement during two-portal endoscopic carpal tunnel release

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Abstract

Background: Although there remain concerns of median nerve damage during endoscopic carpal tunnel release for carpal tunnel syndrome, carpal tunnel pressure variations during Chow's two-portal techinique have not been well investigated.

Methods: We performed a modified two-portal endoscopic carpal tunnel release on 30 patients by inserting a catheter pressure transducer into the carpal tunnel for continuous pressure measurement during the procedure. Grip and pinch strengths, Semmes-Weinstein monofilament test, and nerve conduction studies were examined preoperatively and at postoperative 1, 3, and 6 months. Numbness and the Disabilities of the Arm, Shoulder and Hand score were also evaluated pre and postoperatively.

Findings: Subjective symptoms and nerve conduction study findings improved uneventfully. The pressure was always observed to be maximum pressure immediately before the cannula was withdrawn from the exit portal, and carpal tunnel pressure >300mm Hg was recorded in most of the patients.

Interpretation: A transient increase in the carpal tunnel pressure occurred in all the patients; however, it did not correlate with their clinical outcome or with increased risk of peri-operative complications. Since time-pressure threshold of the median nerve during endoscopic carpal tunnel release is still unknown, our results did not guarantee its safety.

Introduction

Although recent reports on endoscopic carpal tunnel release (ECTR) have shown low complication rates (Chow and Hantes, 2002; Quaglietta and Corriero, 2005; Atroshi et al., 2006; Oertel et al., 2006), there still remains concern regarding damage to the median nerve during insertion of the cannula into the high-pressure carpal tunnel (Arner et al., 1994; Dheansa and Belcher, 1998; Muller et al., 2000; Benson et al., 2006; Uchiyama et al., 2007). Actually we experienced apparent median nerve damage when great resistance was felt by the surgeon during cannula assembly insertion (Uchiyama et al., 2002). Despite these concerns, carpal tunnel pressure variations during ECTR have not been well documented. In this study, we measured the carpal tunnel pressure during our modified two-portal ECTR in order to assess the load on the structures inside the carpal tunnel during the procedure.

We hypothesized that this procedure resulted in a transient increase in pressure, especially when the cannula assembly was introduced into the carpal tunnel.

Materials and Methods

Thirty-four consecutive patients with idiopathic carpal tunnel syndrome (CTS) were enrolled at the institution. ECTR was performed on 34 hands of these 34 patients by our modification of Chow's two-portal technique. Patients with additional complicating factors, such as cervical myelopathy, previous carpal tunnel surgeries, and systemic diseases like rheumatoid arthritis, were excluded from the study. The ethical committee of our institution approved the study protocol. A written informed consent was obtained from all

patients. CTS was diagnosed based on clinical history, physical examination findings, nerve conduction studies, and magnetic resonance imaging (MRI).

Physical examination included recording of the area of sensory disturbance, grip and key pinch strength, and the presence of trigger finger. Grip strength was measured using a Smedley hand dynamometer (Igarashi Ikakougyou Co. Ltd., Tokyo) and pinch strength, using a Pinch gauge (Fuji Seiko Co. Ltd., Nagoya). Each measurement was performed 3 times, and the average value was used for analysis.

The Semmes-Weinstein monofilament test (SW) was conducted on the middle and little fingers. Nerve conduction studies (NCS) were performed using Neuropack MEB-5504 (Nihon Kohden, Tokyo) as described previously (Uchiyama et al., 2002). The motor distal latency (MDL), compound muscle action potential (CMAP) amplitude, sensory conduction velocity (SCV), and sensory nerve action potential (SNAP) were recorded. In our institution, the normal value of MDL was defined as <4.4 ms and that of SCV, as >44 m/s. The reproducibility and accuracy of measurement have been described previously (Uchiyama et al., 2002). Based on NCS, the pre-operative severity of the disease was classified into 5 stages (Uchiyama et al., 2005), which was similar to Padua's (Padua et al., 1997): normal, MDL <4.4 ms and SCV ≥44 m/s; mild, MDL <4.4 ms and SCV <44 m/s; moderate, MDL ≥4.4 ms and SCV <44 m/s; severe, MDL ≥4.4 ms and no response on SCV measurement; and extreme, no response on both MDL and SCV measurement. On wrist MRI, proximal swelling of the median nerve showing a high signal intensity and palmar bowing of the transverse carpal ligament (TCL) at the level of the hook of the hamate were consistent with idiopathic CTS. The disability of the arm, shoulder, and hand

(DASH) score of each patient was recorded.

Four patients were excluded from the analysis. In 3 patients, the transducer stopped functioning during the procedure. In 2 patients, the carpal tunnel pressure recorded by the transducer was 2000~2300 mm Hg when the cannula was introduced and remained at approximately1800mmHg even after withdrawal of the trasducer from the entry portal. In 1 patient, the cable of the transducer was cut using a hook knife during division of the TCL. In 1 patient, the procedure was altered from ECTR to open carpal tunnel release (OCTR) due to poor visualization of the TCL. In this patient, synovial tissue intervened between the slot and the TCL.Thus, a total of 30 hands of 30 patients were analysed. Of these patients, 4 were males and 26 were females, and their age ranged from 27 to 88 years (average, 57 years). The duration of pre-operative symptoms, as reported by the patients, ranged from 1 to 360 months (average, 47 months). Among the 30 hands, the disease was staged as normal in 0 patients, mild in 1, moderate in 5, severe in 23, and extreme in 1 patient. None of the patients were covered under workmen's compensation insurance. On the day after the surgery and at the time of suture removal, i.e. generally 7–9 days after surgery, complaints of newly acquired numbness or increase in numbness were carefully monitored. The patients were supposed to be able to distinguish the numbness related to pre-operative CTS and newly acquired numbness (Arner et al., 1994). At 1, 3, and 6 months post-operatively, physical examination and NCS were repeated, and worsening of the median nerve function, which was defined as aggravation of the MDL, SCV, or numbness, was evaluated. The DASH scores were recorded at 6 months post-operatively. All patients completed their scheduled follow-up visits up to 6 months after surgery.

We used a transducer-tipped catheter in which the strain-gauge catheter-tip pressure sensor was side-mounted at the tip (2-Fr Mikro-Tip catheter pressure transducer, model SPC-320; pressure range:-50 to 300 mm Hg, overpressure range: +4000mmHg or – 760mmHg; Millar Instruments); the catheter was connected to a TC-510 pressure control unit, a passive interface between the catheter pressure transducer and the analog-to-digital converter (PowerLab; AD Instruments). PowerLab CHART 5.0.2 software was used for data analysis (Figure 1). All signals were sampled at 100 Hz. The accuracy of this measurement system has been confirmed in a previous study (Ozerdem and Hargens, 2005). We used total of 4 transducers because the transducers stopped functioning during the procedure in 2 patients and the cable was cut in 1 patinet, as described before. The second transducer was calibrated twice after being used in 20 patients (after 10 measurments each). We sent the trasducer to the manufacturer, who confirmed and guaranteed that the instrument was accurate.

Surgical technique (Uchiyama et al., 2007)

The surgery was performed under local anaesthesia using a pneumotourniquet around the upper arm and the pressure was set at the systolic pressure + 100 mm Hg. Under direct vision, the forearm fascia that lies proximally over the median nerve and the proximal part of the TCL that lies distally over the median nerve were divided longitudinally for approximately 5 to 10 mm through an entry portal of 1 cm, which was made over the proximal wrist crease. An exit portal of 1 cm was made over the triangular zone located immediately distal to the distal edge of the TCL. The palmar fascia was divided transversely for 5 mm to identify the distal edge of the TCL, which sometimes extends

distally as a thin fascial layer. Under direct vision, the distal part of the TCL was divided for approximately 5 to 8 mm. A curved dissector was inserted from the entry portal until it appeared at the distal edge of the TCL. An 18-gauge intravenous catheter was used to facilitate insertion of the pressure transducer. The pressure transducer was inserted first into the 18-gauge catheter until its tip reached the tip of the catheter. The 18-gauge intravenous catheter along with the pressure transducer was then placed longitudinally over the palm so that its tip was at the level of the hook of the hamate. The catheter was then marked at the level of the entry portal. The catheter along with the pressure transducer was now inserted into the carpal tunnel over the median nerve until the marking on the catheter reached the entry portal. Care was taken to place the tip of the catheter on the volar side of the median nerve at the level of the hook of the hamate, and the catheter was retrieved, leaving the transducer inside the carpal tunnel (Figure 3). The cable of the transducer was attached to the skin using adhesive tape so that it would not slide distally during the insertion of the cannula assembly. The first measurement of carpal tunnel pressure was performed with the wrist in the neutral position. The cannula assembly was then inserted into the carpal tunnel after the start of the second successive measurement by the pressure transducer. After the cannula assembly was withdrawn out of the exit portal and the obturator was retracted, the hand was mounted on a hand holder with the wrist and fingers in extension. Carpal tunnel release was completed arthroscopically by simply connecting the 2 divisions proximally and distally using a hook knife. After the cannula was withdrawn, an endoscope was inserted into the entry to examine the median nerve and the cut edges of the TCL along the entire course of the carpal tunnel. At this time, pressure

measurement was completed.

The cross-sectional area of the carpal tunnel was measured from T2 MRIs of all wrists using an NIH Image software; area measurement was carried out by the third author, who was blinded to the results of the pressure measurement, at the level of the hook of the hamate, where the carpal tunnel is the narrowest. Measurements were performed 3 times, and the average value was used for analysis. The protocol of MRI and the details of the measurement procedure have been described previously (Uchiyama et al., 2005).

The first author intra-operatively assessed the resistance to the introduction of the cannula assembly or the ease of access and rated it as ‘easy’ or ‘tight’. This rating was determined only by the surgeon’s subjective assessment of the tightness experienced by his right hand that held the handle of the obturator.

Statistical methods

The effect of post-operative duration on the MDL, CMAP amplitude, SW values, and grip and pinch strengths was evaluated using repeated measures analysis. The pre- and post-operative DASH scores were compared using a paired *t*-test.

The cross-sectional carpal tunnel area at the level of the hook of the hamate was compared between the easy and tight groups using unpaired *t*-tests. The maximum pressure in the carpal tunnel during the procedure and the average pressure in the carpal tunnel when the hand was mounted on the hand holder were correlated with the corss sectional area of the carpal tunnel at the level of the hook of the hamate level and pisiform.

Because accurate measurement could only be achieved at a pressure of -5 to 300mmHg, the data of the patients with pressures > 300mmHg were excluded from the statistical analysis.

A p value of less than 0.05 was considered to be statistically significant.

Results

The introduction of the cannula assembly was rated as easy and tight in 14 and 16 hands, respectively.

The average carpal tunnel pressure before insertion of the cannula assembly with the wrist in the neutral position was 36 mm Hg (standard deviation (SD), 21; range, 5–85 mm Hg). The average time from the insertion of the cannula assembly to its withdrawal from the exit portal was 41.5 s (SD, 17.4; range, 18–85 s), and the time required for division of the TCL when the hand was mounted on the hand holder was 86.0 s (SD, 40.6; range, 25–170 s).

The average cross-sectional area of the carpal tunnel at the level of the hook of the hamate in the easy and tight groups was 162 mm^2 (SD, 17; range, 139–215 mm^2) and 149 mm^2 (SD, 9; range, 127–162 mm^2), respectively. This difference was significant ($p = 0.0196$).

In all cases, the pressure was noted to be maximum immediately before the cannula was withdrawn from the exit portal. In the case of 28 patients, the maximum pressure recorded was > 300 mm Hg (Table 1).

In the case of 10 patients, the average carpal tunnel pressure when the hand was mounted on the hand holder was > 300mmHg. The average pressure in the case of all the patients, except in the case of the 10 abovementioned patients, was 80.3 mmHg (SD, 40.6; range, 29–203 mmHg). The average pressure was not sigificant correlated with the cross sectional area of the carpal tunnel either at the level of the hook of the hamate (correlation coefficient:0.09, $p = 0.72$) or at the pisiform (-0.129, $p = 0.60$).

Figure 3 shows the raw data of carpal tunnel pressure during the procedure in one of the representative cases.

The patients resumed their daily activities at an average of 14 d after surgery (range, 1–28 d). All patients had the complaint of numbness before surgery; however, up to the time of suture removal, none experienced worsening of pre-operative numbness or newly acquired numbness. At the time of suture removal, numbness disappeared in 6 patients, decreased in 16 patients and remained unchanged in 8 patients. At 1 month after surgery, numbness disappeared in 15 hands, decreased in 13 hands, and remained unchanged in 2 hands. At 3 months after surgery, numbness disappeared in 20 hands, decreased in 8 hands, and remained unchanged in 2 hands. At 6 months after surgery, numbness disappeared in 27 hands and decreased in 3 hands. Again, no patient complained of newly acquired numbness after surgery during the course of post-operative follow-up.

The results of grip strength, pinch strength, MDL, and CMAP amplitude measurement are listed in Table 2. MDL improved gradually with time ($p < 0.0001$). Grip and pinch strength improved at 6 months after surgery.

The DASH score improved from 31.6 to 14.8 at 6 months post-operatively ($p < 0.0001$). Overall, the post-operative subjective and objective findings improved uneventfully.

Discussion

The principal finding of this study was that maximum pressure was always recorded immediately before the cannula was withdrawn from the exit portal; however, this technique exerts few adverse effects on the apparent median nerve functions after surgery.

Critics of ECTR are concerned that insertion of the cannula into the diseased and high-pressure carpal tunnel increases the risk of median nerve damage, while advocates of ECTR believe that complications rarely occur if surgeons carefully handle the instruments and have thorough knowledge of the anatomy of the hand (Nagle, 2002). Our results indicate that both these statements are true, and we attempted to elucidate the amount of pressure that could be applied on the structures inside the carpal tunnel, including the median nerve, during ECTR. Several previous studies have measured carpal tunnel pressure at a certain time point before, during, or after ECTR (Schuind, 2002; Okutsu et al, 1989). These measurements were not conducted continuously from the insertion to the completion of the division of the TCL and, particularly, during the introduction of the cannula into the carpal tunnel, when damage to the median nerve is most likely to occur. Povlsen et al. also reported the results of pressure measurement during the Agee single-portal technique (Povlsen et al., 1997); however, their method could not be reproduced, since it was not described in detail. None of the studies have correlated carpal tunnel pressure and the cross-sectional area of the carpal tunnel or the resistance experienced by the surgeon during the introduction of the cannula assembly, which is important to predict the risk of median nerve damage.

It has been suggested that patients with small hands may have increased risk of median nerve damage using Agee's single-portal technique (Dheansa and Belcher, 1998; Schonauer and Belcher, 1999). The pressure increase may be different between the single-portal and two-portal techniques because in the former, the wrist does not need to be hyperextended when the cannula is introduced.

We measured the cross-sectional area of the carpal tunnel at the level of the hook of the hamate on MRI because direct measurement on MRI could more closely reflect the ease of access rather than the measurement of the wrist circumference. Our results failed to show that patients with a smaller cross-sectional area at the level of the hook of the hamate exhibited a considerable increase in the carpal tunnel pressure during introduction of the cannula assembly into the carpal tunnel, because only 2 patients (< 300 mmHg)were available for analysis. The other important factor that may have affected the transient increase in carpal tunnel pressure is synovial hypertrophy. Since the basic pathology of idiopathic CTS has been shown to be related to synovial changes, pre-operative evaluation of the synovium is critical. Since the assessment of the quality of the synovium on the MRI cross-section is not standardized, we did not analyse its effect on pressure values in this study.

Average carpal tunnel pressure when the hand was mounted on the hand holder did not correlate with the cross-sectional area of the carpal tunnel in the case of 20 patients. Other factors, such as synovial hypertrophy or the extent of the division of the TCL before insertion of the cannula assembly, may have some effects on the pressure variations.

Although worsening of symptoms or of nerve conduction study findings were not observed, the possibility of median nerve damage to some extent during the procedure cannot be ruled out. In animal experiments, low-magnitude extraneural compression of 50 mm Hg or more for 2 min was found to alter nerve structure and function (Rempel et al., 1999). A pressure of 150 to 300 mm Hg by cuff inflation caused local conduction blocks of the

peripheral nerve (Lundborg, 1988). A pressure of 50 to 60 mm Hg or more was sufficient for complete blockade of nerve conduction inside the carpal tunnel after 25–50 min, and 50 mm Hg represented the lower critical pressure (Lundborg et al., 1982; Gelberman et al., 1983). These changes may be transient and reversible. In the present study, the possible pressure applied to the median nerve during ECTR was greater and far beyond these values; as a result, structural changes were induced in the nerve, but a duration under pressure was very short. This may be one of the reasons why median nerve damage, if any, did not manifest.

A structurally damaged nerve can revert back to normal function, suggesting a good level of resistance of the peripheral nerves against crush injury (Chen et al., 1992; Kuzis et al., 1999; Kobayashi et al., 2003). However, since the precise characteristics of this time-pressure threshold, which causes permanent damage either to normal or chronically entrapped median nerve, are unknown, surgeons should always attempt to reduce the resistance during the introduction of the cannula assembly.

The pressure transducer used in the present study is very precise and sensitive, and its accuracy for interstitial fluid pressure measurement has been proved to be good. Since the transducer was mounted at the tip of the cable and could be inserted into the carpal tunnel, subtle changes in the contact phenomena between the transducer and the cannula assembly can be readily recorded. The transducer could record the exact moment when it was pushed by the tip of the cannula assembly. This is why we observed instantaneous increases or decreases in pressure, as shown in Figure 3. However, this transducer can

accurately record pressures between -5 and 300mmHg; thus, the transducer may not be suitable for this type of an experiment. The maximum pressure was considerably higher than 300 mmHg for most of the patients. The extent to which the maximum pressure increased during the introduction of the cannula assembly into the diseased carpal tunnel remains unknown. Although the transducer recorded > 2000mmHg of pressure in most of the patients, the data of these patients were not anlyzed because the accuracy of values higher than 300 mmHg was questionable.

Goss and Agee (2009) recently showed that the average peak value of pressure was 1151mmHg (maximum, 2500mmHg) at maximum grip strength in the case of CTS patients. The pressure transducer used was the same as that used in this study. This value is remarkably greater than that determined in a previously study.

The values they recorded in their study were out of the range of -50 to 300 mmHg. Further study is necessary to record the pressure changes during ECTR by using a transducer that can record pressures of > 2500mmHg.

It should be noted that the pressure recorded in this study did not always apply to the median nerve. Some may argue that the pressure measured here could have been falsely elevated, particularly, if the cannula, which may have been placed against the hook of the hamate, exerted any direct pressure on the transducer and the hook of the hamate. Although we cannot completely deny this possibility, this was unlikely to occur because the following reasons. The transducer was carefully placed over the median nerve, not next to the hook of the hamate. Moreover, the cannula was never placed against the hook of the

hamate but immediately under the TCL. The MRI cross-section of the bulging carpal tunnel clearly shows that direct contact between the transducer and the hook of the hamate cannot be achieved because of the presence of flexor tendons covering the entire bony aspect of the hook of the hamate. We believe the value of the pressure transducer shown in this study did not result from the cannula pinching the transducer against the hook of the hamate; in fact, it resulted from the pressure on the median nerve, flexor tendons, and/or TCL.

In conclusion, the pressure was always observed to be maximum pressure immediately before the cannula was withdrawn from the exit portal, and carpal tunnel pressure >300mm Hg was recorded in most of the patients; however, it did not correlate with their clinical outcome or with increased risk of peri-operative complications. Since time-pressure threshold of the median nerve during endoscopic carpal tunnel release is still unknown, our results did not guarantee its safety.

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Figure Legends

Figure 1.

A: A transducer-tipped catheter in which the strain-gage catheter-tip pressure sensor is side-mounted at the tip (2-Fr Mikro-Tip Pressure Transducer Catheter, model SPC-320, Millar Instruments)

B: The catheter is connected to the TC-510 pressure control unit, which is a passive interface between the catheter pressure transducer and the analog-to-digital converter (PowerLab, ADInstruments). PowerLab CHART 5.0.2 software is used for data analysis.

Figure 2.

The pressure transducer catheter is inside the carpal tunnel. The tip is at the hook of the hamate level. It is inserted after partial division of both the distal and proximal parts of the

transverse carpal ligament.

Figure 3.

A representative case of raw data of carpal tunnel pressure during the procedure (patient number 18 in Table 1). The pressure inside the carpal tunnel at the resting position was 64 mmHg. The first arrow indicates the time when the cannula assembly was inserted into the carpal tunnel. A maximum pressure (300mmHg <) was recorded when the cannula assembly was about to be pulled out of the exit portal. The tip of the cannula could push the pressure transducer at this instance. The second arrow indicates the time when the hand was mounted on the hand holder and the division of the transverse carpal ligament was started arthroscopically. The third arrow indicates the time when the division of the ligament was completed, and the pressure abruptly decreased, indicating decompression of the median nerve.

Table 1: Patients characteristics and values of pressure measurement

No	age	sex	severity	ICTP	Max	Ave.Pr.	S2	S3	Resistance
1	61	F	severe	29	300<	300<	176	139	tight
2	72	F	severe	72	300<	300<	180	149	tight
3	75	F	severe	9	300<	57	168	154	tight
4	75	F	severe	44	300<	111	188	161	tight
5	54	F	severe	27	300<	133	162	147	tight
6	79	F	sever	5	300<	29	157	127	tight
7	63	F	severe	16	300<	95	182	155	tight
8	47	M	severe	39	300<	62	211	162	tight
9	58	F	mild	32	300<	300<	178	143	tight
10	63	F	severe	45	300<	300<	170	147	tight
11	69	F	mod	7	300<	53	169	156	tight
12	59	F	severe	55	300<	300<	169	150	tight
13	43	F	mod	15	300<	300<	179	153	tight
14	55	F	extreme	19	300<	300<	179	147	tight
15	51	F	severe	31	300<	68	188	153	easy
16	47	F	severe	53	300<	129	174	164	easy
17	56	F	severe	31	300<	100	180	150	easy
18	43	F	severe	64	300<	300<	175	139	easy
19	49	F	mod	44	300<	65	194	163	easy
20	44	F	severe	15	300<	102	183	159	easy
21	55	M	mod	30	300<	49	209	171	easy
22	54	F	mod	25	300<	58	204	154	easy
23	69	M	severe	60	300<	300<	261	215	easy
24	62	F	severe	36	300<	41	168	156	easy
25	67	F	severe	39	300<	67	180	153	easy
26	78	F	severe	49	300<	50	186	166	easy
27	47	F	severe	32	199	64	191	157	easy
28	78	F	severe	64	300<	203	179	153	easy
29	66	M	severe	6	295	69	184	183	easy
30	64	F	severe	85	300<	300<	177	156	easy

mod:moderate stage, ICTP:intracarpal tunnel pressure (mmHg),
Max:Maximum intracarpal tunnel pressure (mmHg),
Ave.Pr:average pressure during the hand on the hand holder(mmHg),
S2: cross sectional area at the pisiform level, S3:at the hook of the hamate level(mm^2),
300< indicates the pressure recorded more than 300mmHg.

Table 2　Effect of time after surgery on the improvement of grip strength, pinch strength, SW, MDL, and CMAP amplitude.

	PreOpe	1 month	3 months	6 months
Grip strength (kg)	17.1 (8.0)*	11.3 (6.5)	16.0 (6.0)	18.3 (6.5)*
Pinch strength (kg)	5.7 (1.7)*	5.3 (1.2)	5.7(1.4)	6.4 (1.6)*
SW	3.69 (0.67)*	3.07 (0.45)*	3.16(0.47)	3.00 (0.33)
MDL (ms)	7.4 (2.0)	5.6(1.2)	4.8 (0.8)	4.4 (0.6)
CMAP amplitude (mV)	7.8 (4.4)*	8.3(4.7)	8.7(4.8)	9.6(5.2)*

All the values are shown as mean(standard deviation). Grip strength, pinch strength, and CMAP amplitude significantly improved at 6 months after surgery. *: $p < 0.01$

MDL improved gradually with time ($p < 0.0001$). SW significantly improved at 1 month after surgery ($p < 0.0001$).

PreOpe: preoperative, SW: Semmes-Weinstein monofilament test, MDL: motor distal latency, CMAP: compound muscle action potential.

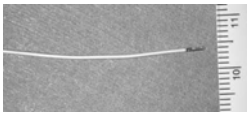

Figure 1A.

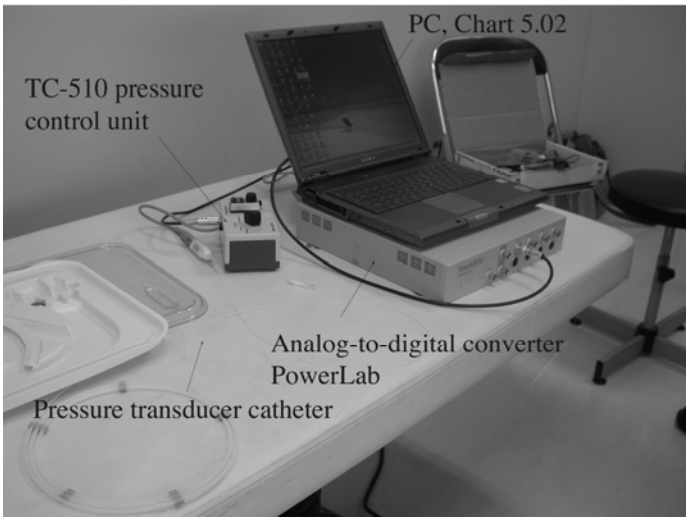

Figure 1B.

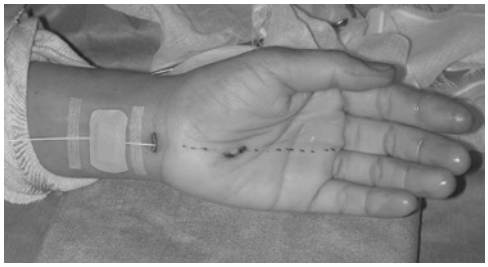

Figure 2.

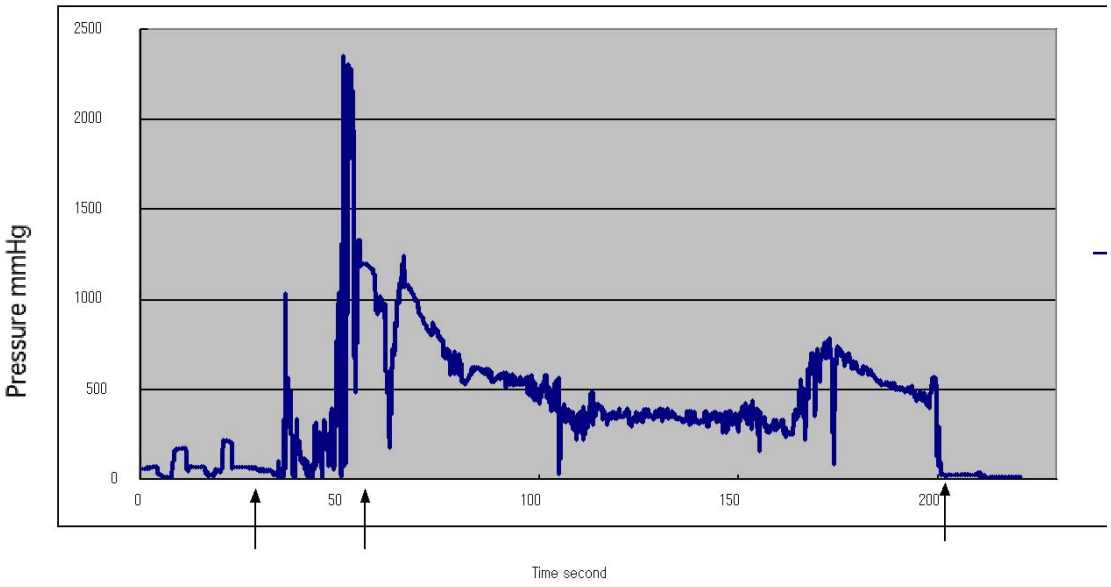
2500
2000
1500
1000
500
0
Pressure mmHg
0
50
100
150
200
Time second

Figure 3.