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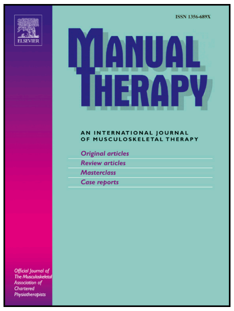


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Wai Keung Christopher Lai, Yin Ting Chiu, Wing Sze Law

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# The deformation and longitudinal excursion of median nerve during digits movement and wrist extension

***Lai, Wai Keung Christopher*** [a*] **Chiu*, Yin Ting*** [b] ***Law, Wing Sze*** [c]

[a] Department of Health Technology and Informatics,The Hong Kong Polytechnic University, Hung Hom, HKSAR, China;

[b] Department of Radiology, The Pamela Youde Nethersole Eastern Hospital, Chai wan, HKSAR, China;

[c] Department of Radiology, Tuen Mun Hospital. Tuen Mun, HKSAR, China.

*** Corresponding author:**

Dr. Lai, Wai Keung Christopher

Address for correspondence:

Department of Health Technology and Informatics, The Hong Kong Polytechnic University, Hung Hom, HKSAR, China.

Email: chris.lai@polyu.edu.hk

Tel: +852-3400-8596

Fax: +852-2362-4365

**Abstract**

The use of electronic devices, such as mobile phones and computers, has increased drastically among the young generation, but the potential health effects of carpal tunnel syndrome (CTS) on university students has not been comprehensively examined. Thirty-one university students aged 18 to 25 y with no symptoms of CTS were successfully recruited in this study. By using noninvasive ultrasonography, the morphological characteristics of the median nerve of each volunteer, and the extent of its longitudinal excursion movement under experimental conditions, in which a real operating environment of electronic devices was simulated, were quantified. The results demonstrated that the median nerve at the carpal tunnel inlet was flattened during wrist extension: the flattening ratio increased from 3.40 ± 0.91 at the neutral position to 4.10 ± 1.11 at the angle of 30° and 4.09 ± 1.11 at the angle of 45°. In addition, the median nerve became swollen after the students performed rapid mobile-phone keying for 5 min, indicated by a significant increase in the cross-sectional area from 6.05 ± 0.97 $mm^2$ to 7.56 ± 1.39 $mm^2$. Passive longitudinal excursion was observed at the median nerve when the students performed mouse-clicking (2.4 ± 1.0 mm) and mobile-phone keying tasks (1.7 ± 0.6 mm), with the mouse-clicking task generating a greater extent of longitudinal excursion than the mobile-phone keying task did. In conclusion, the findings of the present study verify the potential harm caused by using electronic devices while maintaining an inappropriate wrist posture for a substantial period.

## 1. Introduction

Carpal tunnel syndrome (CTS) is a progressive painful condition that occurs at the wrist, and is caused by a combination of factors that are associated with increased carpal pressure such as trauma or injury, diabetes, rheumatoid arthritis, acromegaly, hypothyroidism, and pregnancy (Silman et al. , 1993). In addition to these factors, repetitive wrist-hand movements, especially involving digit movement combined with extension, ulnar deviation, or external compression at the wrist, increase the risk of CTS (Fagarasanu and Kumar, 2003, Palmer et al. , 2007, Thomsen et al. , 2008). Ali and Sathiyasekaran (2006) demonstrated that year-long exposure to computer work and the long working hours of computer workers were risk factors for CTS (Ali and Sathiyasekaran, 2006). Therefore, with the growing availability and excessive use of electronic devices such as mobile phones and computers, the effects on health have become a concern because certain patients with CTS are idiopathic and exhibit no definite contributors such as synovitis or other compressive conditions of the wrist (Wright et al. , 1996).

In Hong Kong, the increased availability of computers has resulted in extremely high usage. Students are using computers to perform various tasks including word processing, gaming, and searching for information on the Internet (Kent and Facer, 2004). Approximately two-thirds of U.S. high school students aged 16–18 y were reported to use their computer for more than 4 h per d (Sommerich et al. , 2007), whereas in Hong Kong, students aged 12–16 y reported an average of 2.5 h per d (Ho and Lee, 2001). Therefore, the finding that students are using electronic devices for substantial periods from an early age is not surprising.

The emerging study of the morphological changes and gliding movement of the median nerve is crucial for the identification of CTS risk markers. When the median nerve is under increased carpal tunnel pressure, it typically becomes swollen and flatten (Klauser et al. , 2009). Moreover, previous studies have reported that the median nerve of symptomatic CTS subjects exhibited a large cross-sectional area (CSA) (Lopes et al. , 2011)and high flattening ratio (FR—the ratio of the transverse diameter over the anteroposterior diameters of the median nerve) (Chan et al. , 2011) , although such associations were generally confounded by the body mass index (BMI) and wrist circumference measurements (Moghtaderi et al. , 2005). In addition, Burgess-Limerick et al. (1998) indicated that when the wrist was extended, the carpal tunnel pressure increased because of the constricted space in the carpal tunnel, which exerted increased force onto the median nerve (Burgess-Limerick et al. , 1999).

Recently, the application of B-mode ultrasonography was determined to be useful in the measurement of nerve deformation. Although it is a noninvasive and readily available imaging tool used in neuromusculoskeletal imaging, the current use of this tool in the clinical diagnosis of CTS is limited. Ultrasound can be used to evaluate morphological changes and identify certain focal lesions on the median nerve, but it fails taking into the consideration of the capacity of median nerve to glide during wrist-hand movements.

The longitudinal movement of the median nerve is a type of movement that cannot be quantified directly using B-mode ultrasound because of the lack of a distinct marker for tracking. In addition, when the longitudinal movement of the median nerve is perpendicular to the transmission of the ultrasound, tracking the moving echo-reflecting interfaces accurately is difficult. Therefore, directly measuring the longitudinal excursion of the median nerve remains challenging.

Nevertheless, spectral Doppler ultrasonography is a possible method for determining the longitudinal excursion of the median nerve indirectly by using a pixel analysis program (Echigo et al. , 2008). Because the extent of longitudinal excursion of the median nerve measured using spectral Doppler ultrasonography was mathematically equal to the total number of calibrated pixels within the area of a spike in the velocity-time integral spectrum, the corresponding longitudinal excursion of the median nerve could, therefore, be calculated indirectly in this study (Figure 1).

Therefore, the objectives of the present study were to determine the following:

1. Whether extension at the wrist (a common posture adopted during the use of mobile phones and a computer mouse) is related to morphological changes (cross-sectional area and flattening ratio) in the median nerve;
2. The effect of a substantial period of intense mobile phone use (performing a rapid keying task for 5 min) on morphological changes in the median nerve; and
3. The extent to which the median nerve demonstrates passive longitudinal excursion during the use of mobile phones and computers.

## 2. Methods

### 2.1 Subjects

Thirty-one Chinese volunteers aged 18–25 y were recruited from the Hong Kong Polytechnic University. The inclusion criteria of the present study were (1) Chinese ethnicity, (2) university student, and (3) right handed. The exclusion criteria included

(1) subjects with symptoms of CTS including pain, tingling, burning, numbness, or a combination of these symptoms in relation to the palmar aspect of the thumb, index finger, middle finger, or radial half of the ring finger (Katz and Simmons, 2002); (2) subjects with a history of wrist surgery including carpal tunnel injection or fracture within past 10 y; (3) subjects with a history of underlying conditions associated with CTS including diabetes mellitus, rheumatoid arthritis, pregnancy, acromegaly, and hypothyroidism; (4) subjects exhibiting anatomic variations in the median nerve, such as bifurcation, which were identified during the ultrasound experiment (Wong et al. , 2002); (5) obese subjects, determined by a BMI> 25kg/m$^2$(Moghtaderi, Izadi, 2005); and (6) subjects who engaged in exercise involving their upper arm, such as weight lifting, boxing, racket sports, and cycling, within 1 wk prior to the examination.

## 2.2 Materials

Ethical approval was obtained from the local research committee and informed consent was obtained from each participant. A Philips ultrasound unit (Model: HD11 XE, Philips Medical Systems, Bothell, WA, USA) with an L12-5 linear array transducer was used in this study. A trained sonographer (MC) performed all ultrasound measurement and another 2 researchers (KL and KC) conducted the image analysis of all the resultant images.

## 2.3 Procedures

### 2.3.1 Wrist extension

The CSA and FR of the carpal tunnel inlet in the right wrist were first examined using B-mode ultrasound, which was similar to the technique described in a similar previous study (Toosi et al. , 2011), and the measurement was repeated at 4 distinct wrist extension angles (0°, 15°, 30°, and 45°) without the participants performing any specific activity during the process. The values measured at the neutral position (wrist extension angle at 0°) will be used as reference and compared with the values measured from 15°, 30° and 45° respectively. During the examination, the volunteers were asked to sit on a chair with the right side of their shoulder slightly abducted, elbow flexed at 90°, and forearm resting on the table with the wrist fully supinated and the digits fully extended. After the morphological changes in the median nerve were measured at 4 distinct wrist extension angles, the longitudinal excursion of the median nerve was subsequently measured during the mouse-clicking and mobile-phone keying tasks.

### 2.3.2 Mouse-clicking task

The volunteers were asked to maintain the postured described in 2.3.1, except their wrist was pronated in this examination. They were then instructed to click a computer mouse 5–10 times using their right index finger according to the beat generated by a metronome (80 beats/min). The median nerve in the longitudinal section at a site approximately 3–4cm distal to the crest of the subject's right elbow was identified using B-mode ultrasound. A Doppler range gate was then positioned over the median nerve to detect changes in the velocity of the median nerve during mouse clicking. The longitudinal excursion of the median nerve was measured at this level rather than at the wrist because the transverse movement of the median nerve at this level was reduced, and the surrounding muscles and tendons were not easily included in the sample volume, which would have affected the accuracy of Doppler sampling (Hough et al. , 2000). After at least 3 consecutive spikes were generated on the velocity-time integral spectrum by the participants performing the mouse-clicking task, still images were saved and transferred to the pixel analysis program, Scion Image (Scion Corp., Fredrick, Maryland, USA), which was developed by the National Institutes of Health for conducting further analysis (Figures 1 and 2).

2.3.3 Mobile-phone keying

The ultrasound scanning protocol for measuring the extent of longitudinal excursion of the median nerve during the mobile-phone keying task was the same as that used for the mouse-clicking task, except the volunteers were asked to change their wrist posture to partially supinated (approximately 45°supinated) to enable them to assume a posture generally applied when using a mobile phone for text messaging (Figure 3). They were provided with a mobile phone without a touchscreen (Sony Errison K750i) and were asked to simulate text messaging by flexing their right thumb and pressing the number 5 button on the keypad 5–10 times according to the beat generated by the metronome (80 beats/min). Again, at least 3 consecutive spikes on the velocity-time integral spectrum were required for further analysis using Scion Image.

2.3.4 Five-min rapid keying on a mobile phone

After successfully measuring the longitudinal excursion by performing spectral Doppler ultrasound, the subjects were asked to perform a rapid keying task using the same mobile phone. They were instructed to press the number 5 button rapidly as many times as possible for a period of 5 min. After completing the rapid keying activity, the flattening ratio and cross-sectional area of the median nerve at the carpal tunnel inlet of the wrist were evaluated at 0° of wrist extension by using B-mode ultrasound.

2.4 Data Analysis

The CSA and FR were measured offline by manually tracing the boundary of the median nerve and its corresponding axes (Figures 4 and 5). Similarly, by manually tracing the boundary of the velocity-time integral spectrum shown in the image, the area under the velocity-time integral spectrum could be determined using the pixel analysis program. SPSS Statistics software (IBM, version 18) was used for conducting all statistical analysis. A generalised linear model repeated measures analysis of covariance (ANCOVA) adjusted for sex and BMI (posthoc test with Bonferroni adjustment) was used for comparing the mean difference in CSA and FR at various wrist angles. A *t*-test was used to determine the mean difference in the longitudinal excursion that occurred during the mouse-clicking and mobile-phone keying tasks, and the mean difference between the results obtained before and after rapid keying. All parameters were represented by mean±standard deviation and the level of significance was set at 0.05. Because the ultrasound measurement and pixel analysis were highly dependent on an operator, intraclass correlation analysis was performed to determine the intrarater variation in the ultrasound measurement of the CSA over 10 cases, and the intrarater and interrater variation in longitudinal excursion between the pixel analysis results obtained over 10 cases and 12 cases, respectively.

## 3. Results

The interrater and the intrarater class correlation derived from the pixel analyses of the longitudinal excursion were 0.96 and 0.96, respectively, whereas the intrarater correlation of the CSA measurement was 0.98. The demographic details of the study population are summarised in Table 1. Thirty-one university students with a mean age of 21.7±1.5 y, a female to male ratio of 11:20, and a mean body-mass index of 19.60 ±2.15kg/$m^2$ were recruited.

The morphological changes in the median nerve at various degrees of extension at the wrist are summarised in Table 2. No significant difference in the CSA of the median nerve occurred between the various intervals of wrist extension angle (6.05–6.13$mm^2$). Nevertheless, a significant increase in the FR at 30° of wrist extension (4.10±1.11, $P$ <0.01) and 45° of wrist extension (4.09±1.11, $P$=0.01)) was observed when compared with that at the neutral position (3.40±0.91) (0° of wrist extension).

Both the mobile-phone keying and mouse-clicking tasks affected the median nerve and resulted in various degrees of longitudinal excursion, with the mouse-clicking task (2.4±1.0 mm) generating greater longitudinal movement ($P$ <0.01, F=16.53) than the mobile-phone keying task did (1.7±0.6 mm) (Figure 6).

Finally, after the participants performed the rapid keying task on a mobile phone for 5min, the morphological changes in the CSA and FR of the median nerve were measured again (Table 3). The results indicated that a significant increase in the CSA occurred (from 6.05±0.97 $mm^2$to 7.56±1.39$mm^2$, $P$ <0.01) but not in the FR (from 3.40±0.91 to 3.54±1.13, $P$=0.55).

**4. Discussion**

The mean CSA of the median nerve in the present study had a relatively smaller value (6.05$mm^2$) compared with that reported in previous studies (mean CSA ranged from 10.1–14.3$mm^2$) (Allmann et al. , 1997, Moghtaderi, Izadi, 2005, Toosi, Impink, 2011). This can be partially explained by the smaller mean BMI of the population used in the present study; most previous studies have been conducted using people of European descent who were generally taller and had a heavier build than the Chinese people who participated in this study.

Substantial deformation was observed when the wrist had extended to 30°and 45°. The median nerve was compressed by extension, and it elongated or glided to a limited extent because of increased traction (Keir and Rempel, 2005) and became flattened (Topp and Boyd, 2006). Kuo et al. (2001) determined that the neutral wrist position is associated with minimal median nerve compression (Kuo et al. , 2001), whereas Liu et al. (2003) demonstrated that computer users who type using an extended wrist posture have a higher risk of CTS, particularly when the wrist is extended to more than 20°(Liu et al. , 2003). Burgess-Limerick et al. (1998) further supported that wrist extension and ulnar deviation lead to an increase in carpal tunnel pressure by narrowing the space of the carpal tunnel and exerting a force on the median nerve (Burgess-Limerick, Shemmell, 1999, Werner and Andary, 2002). Therefore, the increase in the FR of the median nerve at the level of the pisiform (carpal tunnel inlet) can indirectly reflect the abrupt increase in carpal tunnel pressure that occurs during wrist extension.

In addition to being deformed during wrist extension, the morphology of the median nerve may be affected by rapid digit movement (Massy-Westropp et al. , 2001, Toosi, Impink, 2011). A previous study reported that significant swelling of the median nerve occurred at the carpal tunnel inlet in both the dependent and nondependent hand of a typist after they typed for 60 min (Toosi, Impink, 2011). Keir et al. demonstrated that the carpal tunnel pressure of the majority of participants observed during mouse usage was higher than that of subjects with known alterations in nerve function and structure, indicating that intensively using a computer mouse for a substantial period can increase the risk of neuropathy (Keir and Rempel, 2005).Today, mobile phone is gradually replacing computer to become a necessity at work, communication and entertainment of our daily life. Mobile phone users need to press on the phone screen/keypad to search on the Internet, playing games and sending messages. In particular, text messaging is now the widely used mobile data service, with about 2.4 billion active users at the end of 2007 (Sharan and Ajeesh, 2012). Nowadays, the teenagers tend to communicate using Short Message Service that requires frequent keying stroke for a substantial period of time. They like to play games on the phone, but certain games on mobile phone require them to press on the phone screen/keypad vigorously and continuously for minutes. Therefore, repetitive stress injuries like wrist and finger pain become a new epidemic in teenagers due to overuse of it. In the present study, a substantial increase in the cross-sectional area of the median nerve was observed after the participants performed a rapid keying task for 5 min, indicating that the intensive thumb-tapping activity led to a swelling of the median nerve. Nevertheless, Impink et al. (2009) reported contradictory findings, in which a reduced cross-sectional area was observed after participants engaged in a wheelchair sporting activity (Impink et al. , 2009). We postulate that such discrepancy may be caused by the difference in the nature of the activities: the wheelchair sporting activity involved solely upper-limb exercise and was more vigorous than mouse clicking and rapid keying, leading to a significant increase in carpal tunnel pressure that compensated for the swollen median nerve.

The gliding of the median nerve during digit movement and wrist extension can prevent kinking or stretching, and facilitate the reestablishment of equilibrium when any imbalance in tensile force occurs because of joint motions. During active digit movement, friction may have developed between flexor digitorum superficialis tendons (Topp and Boyd, 2006), and the longitudinal excursion of the median nerve in response to finger and joint movement was considered to be caused by its internal elastic tension (Szabo et al. , 1994). In the present study, we gathered evidence that the median nerve demonstrated passive longitudinal gliding movement during the use of mobile phones and computers, with the mouse-clicking task generating greater longitudinal excursion than the mobile-phone keying task did.

In addition to using the spectral Doppler ultrasonography technique, the speckle tracking ultrasonography technique involving the computational recognition of individual greyscale patterns is another emerging technique for tracking the movements of a particular speckle in an image (Korstanje et al. , 2010). Although this technique has been proposed in several previous studies, using it to measure the median nerve gliding movement was generally determined by its availability. Furthermore, the lack of an identifiable speckle limits the accuracy of tracking the movement of the median nerve. By contrast, the spectral Doppler ultrasonography technique is readily accessible, highly reproducible, and can provide additional information on the kinematic motion of the median nerve. Although the application of the spectral Doppler technique for measuring the longitudinal excursion is still being developed, the accuracy and reliability of this technique in dynamic neuromusculoskeletal imaging are promising.

## 4.1 Limitations

This study has several limitations. First, applying spectral Doppler ultrasound in the investigation of the longitudinal excursion of the median nerve, the transverse movement of the median nerve was not considered. In addition, the deformation of the median nerve in relation to wrist extension greater than 45°was not addressed. Moreover, previous studies indicated that a median nerve becomes swollen immediately after hand activity and returns to its original size within 10 min (Massy-Westropp, Grimmer, 2001, Toosi, Impink, 2011). In the present study, no resting time was provided in between the hand activities. However, because all the study subjects followed a standard protocol and the intensity of the hand activities during the measurement of longitudinal excursion was far lesser than that in the 5-min rapid keying task and the aforementioned pervious studies, the accumulated effect of performing previous activities on morphological changes in median nerve during the 5-min rapid keying task was comparably negligible.

## 5. Conclusion

The setup of the present study was used to ascertain the potential harm of using a computer mouse and a handheld mobile phone in a real operating environment. The findings of the present study further support that the repetitive digit movement and improper posture of the wrist when using electronic devices may impose a high risk of CTS among university students, particularly when using these devices for a substantial period.

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**Conflicts of interest**

There are no declarations of conflicts of interest.

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**Table 1. The demographic details of the study population**

| | N=31 |
|---|---|
| **Age (y)** | **21.7±1.49** |
| **Female to Male ratio** | **11:20** |
| **Body Mass Index (kg/m$^2$)** | **19.60 ±2.15** |

**Table 2. ANCOVA analysis with post hoc test on cross sectional area (CSA) and flattening ratio (FR) of the median nerve at the pisiform level with sex and BMI adjusted**

| Baseline reference value | Mean CSA ($mm^2$) | | Mean FR (no unit) | |
|---|---|---|---|---|
| | **Mean±SD (*P* value)** | **95%CI** | **Mean±SD (*P* value)** | **95%CI** |
| Neutral Position ($0^o$) | 6.05±0.97 | 5.70-6.40 | 3.40±0.91 | 3.07-3.73 |
| | | | | |
| **Degree of wrist extension** | **Mean CSA ($mm^2$)** | | **Mean FR (no unit)** | |
| $15^o$ | 6.06±0.93 (*P*=0.92) | 5.71-6.42 | 3.82±1.10 (*P*=0.15) | 3.42-4.22 |
| $30^o$ | 6.13±0.82 (*P*=0.61) | 5.83-6.43 | 4.10±1.11 **(*P*<0.01)** | 3.70-4.50 |
| $45^o$ | 6.11±0.83 (*P*=0.82) | 5.80-6.42 | 4.09±1.11 **(*P*=0.01)** | 3.69-4.48 |

Comparisons between the reference scan with various wrist positions: ANCOVA analysis with post hoc test demonstrated no significant change in CSA of the median nerve from neutral position (baseline reference value) to various degree of wrist extension. However, a significant increase in flattening ratio of median nerve was observed when the wrist was extended (1) from neutral position to $30^o$ of wrist extension ($P$<0.01, F=18.53), and (2) from neutral position to $45^o$ of wrist extension ($P$=0.01, F=16.36) respectively.

**Table 3. *t*-test analysis on the acute change of cross sectional area (CSA) and flattening ratio (FR) of median nerve after a 5-minute of rapid keying on mobile phone**

| Mobile phone keying | Mean CSA ($mm^2$) | | Mean FR (no unit) | |
|---|---|---|---|---|
| | **Mean±SD (p value)** | **95%CI** | **Mean±SD (p value)** | **95%CI** |
| Baseline measurement | 6.05±0.97 | 5.71-6.40 | 3.40±0.91 | 3.07-3.73 |
| Post measurement (5 minutes rapid keying) | 7.56±1.39 **(p<0.01)** | 7.06-8.07 | 3.54±1.13 (p=0.55) | 3.12-3.96 |

A significant increase in CSA ($P < 0.01$, F = 37.80) but not in FR was observed after the subjects performed the 5-min rapid keying task on a phone.

**Figure 1. The Spectral Doppler ultrasound of the right median nerve during mouse clicking task**

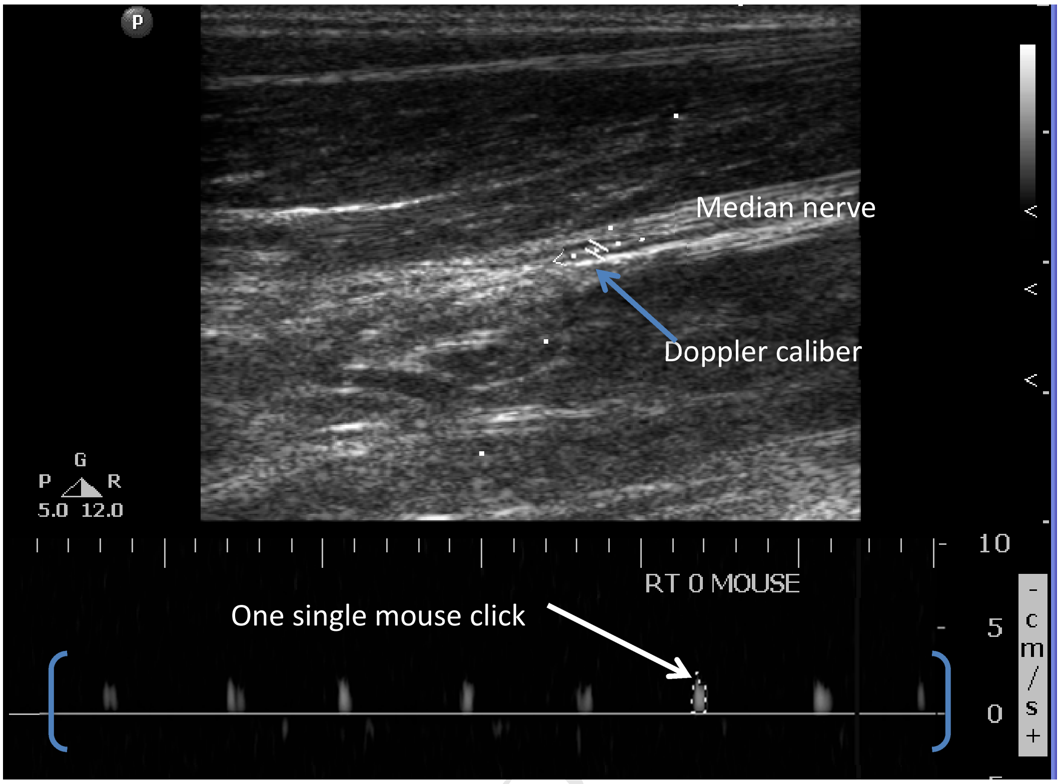
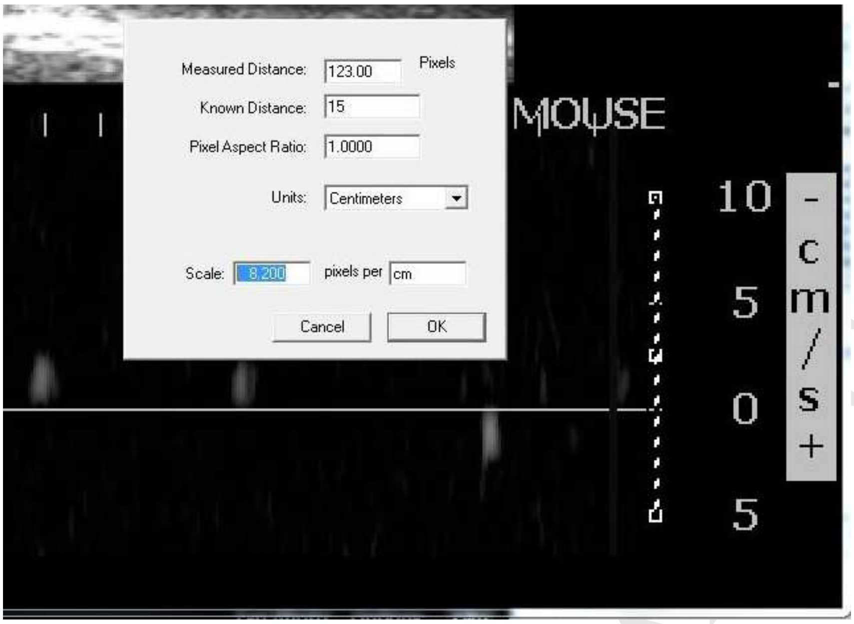
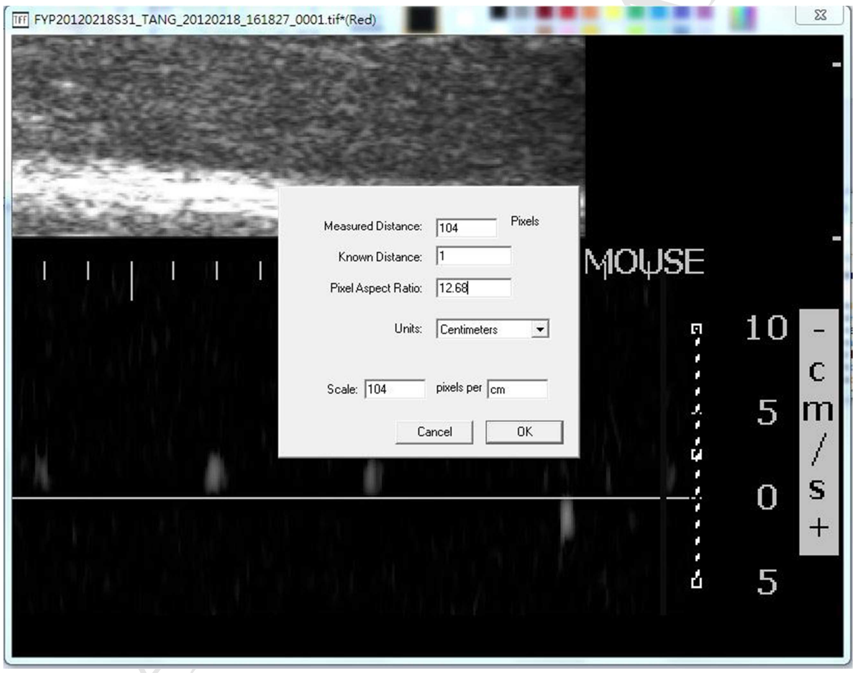



Fig 1 is a still image of median nerve in longitudinal section captured from the ultrasound examination using B-mode and spectral Doppler mode. In this image, the 2-D B-mode information was projected on the upper portion of the still image. The corresponding Doppler signal caused by the movement of the median nerve was projected at the bottom of the image as a spectrum—Doppler velocity (y-axis) over time (x-axis). All Doppler signals were detected by placing a caliber (white dotted line) over the median nerve. As shown in this image, 7 consecutive spikes were detected, corresponding to the longitudinal excursion of the median nerve caused by 7 mouse clicks.

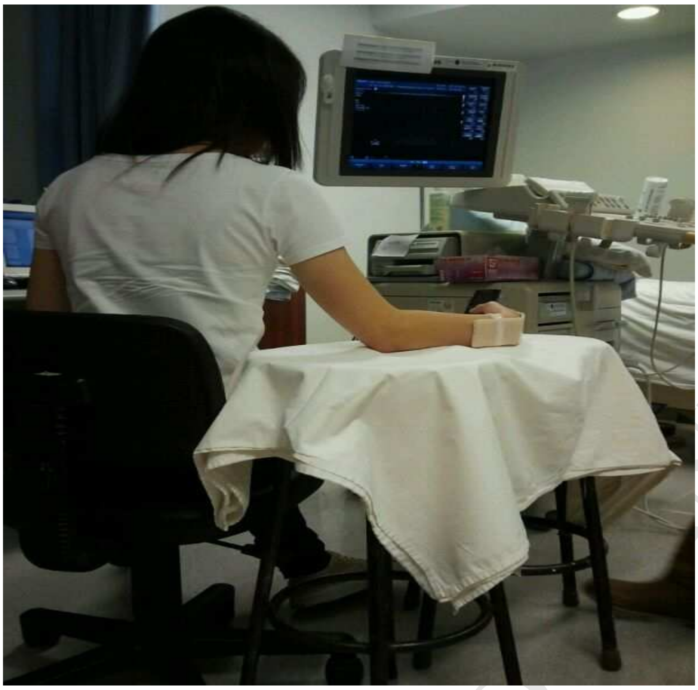
**Figure 2. The calibration process of the pixel size dimension in an image**




By converting the dimensions of each calibrated pixel in an image, the pixel analysis software can determine the actual magnitude of the measured parameters from the Doppler spectrum. (Top) The y-axis of the velocity-time integral spectrum corresponds to the velocity of the Doppler signal. The example shown here indicates that 123 pixels correspond to 15 cm/s and, therefore, the height of the pixel is 0.12 cm/s. (Bottom) The same calibration procedure was repeated on the x-axis (time-lapsed Doppler signal) for calculating the width of the pixel. The example shown here indicates that 104 pixels represent 1 s and, therefore, the width of the pixel is 0.0096 s. Thus, a single pixel in the image represents 0.001152 cm. If a spike on the spectrum contains 100 pixels, the excursion movement is equal to 0.01152 x 100 or 1.15 mm. The calibration process was repeated on every image.

**Figure 3. The sitting posture of the volenteer (a) and the experimental setup of the mobile phone keying task for the measurement of longitudinal excursion (b)**



**(a)**

(b)

(Fig 3a) A volunteer sat on a chair with the right side of her shoulder slightly abducted, elbow flexed at 90°, and her forearm resting on a table. A thermosplint shaped with a predefined angle was used to standardise the angle of wrist extension at 0°, 15°, 30°, and 45°.

(Fig 3b) The forearm of the volunteer was slightly supinated because most people use this posture when using a mobile phone.

**Figure 4. The transverse section of the median nerve at the level of carpal tunnel inlet.**

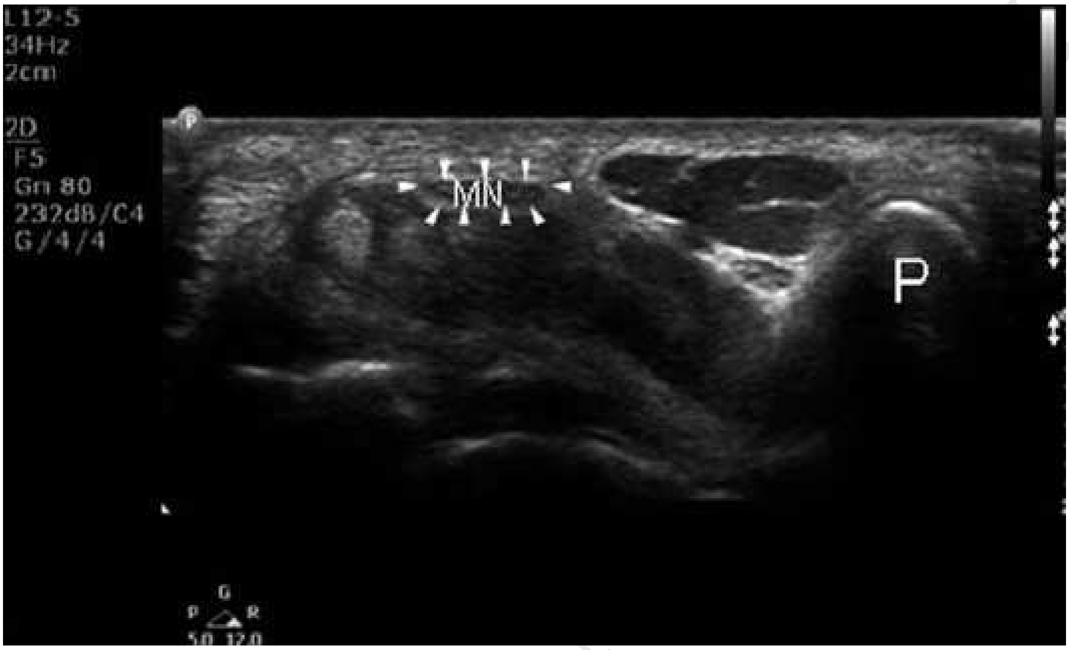



Fig 4 is a transverse section of the wrist captured using 2-D B-mode. The arrowheads indicate the boundary of the median nerve (MN) and (P) represents the pisiform bone.

**Figure 5. The measurement of the CSA and FR of median nerve**

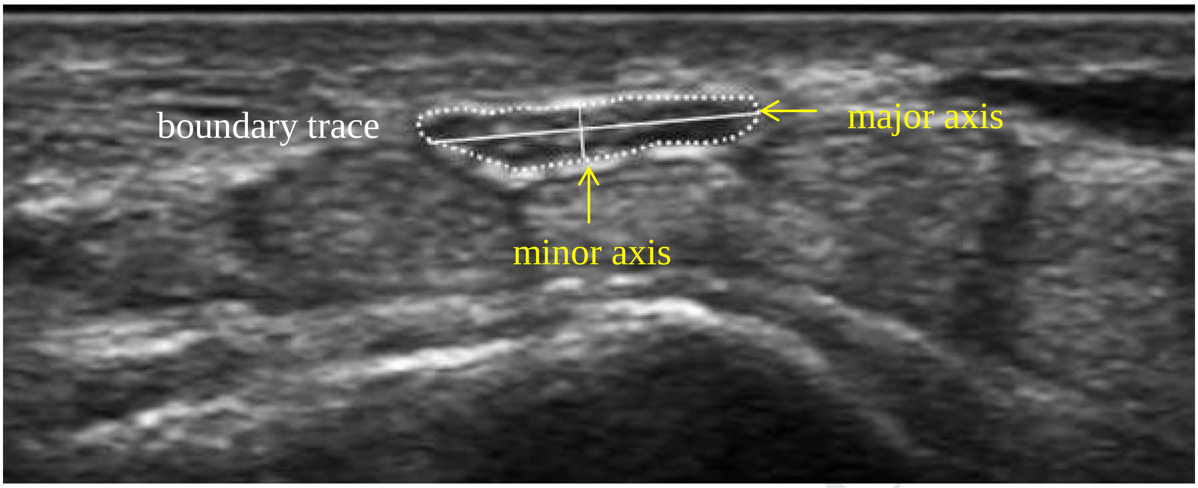



Fig 5 is a transverse section of the wrist captured using 2-D B-mode, with magnification over the median nerve. In this magnified picture, the major axis and the minor axis of the median nerve represent the transverse diameter and the anteroposterior diameters of the median nerve, respectively. The ratio of the transverse diameter to the anteroposterior diameter of the median nerve represents the flattening ratio of the median nerve, whereas the boundary of the median nerve is indicated by the dotted line, and the area under the dotted line represents the CSA of the median nerve.

**Figure 6. An error bar graph showing the mean with 95% CI of the longitudinal excursion movement of the median nerve during mouse clicking task and mobile phone keying task**