Intra-individual variations in the bifurcation of the radial nerve and the length of the posterior interosseous nerve

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1. Introduction

The literature reporting anatomical variations is predominantly focused on inter-individual differences, with few studies investigating the presence of intra-individual anatomical variations (Willan et al., 2002). However, the high prevalence of anatomical variations between individuals suggests variations may be common within individuals.

The radial nerve is an important clinical structure, owing to its complex course and deep position throughout most of its length. One complexity of clinical interest is the location at which the nerve bifurcates to form the superficial branch of the radial nerve and the posterior interosseous nerve. Variations in the location of this bifurcation may plausibly change the way the nerve and its branches respond to the forces applied during clinical tests used for patient examination of the nervous tissue (Butler, 1996; Magee, 2005).

Anatomical literature commonly reports that the radial nerve bifurcates at the level of the lateral humeral epicondyle (LHE) (Mazurek and Shin, 2001; Palastanga et al., 2006; Standring, 2008); however, cadaveric studies have challenged this claim (Sunderland, 1943; Abrams et al., 1997). Many studies have investigated the bifurcation point of the radial nerve in relation to the LHE between cadavers (Linell, 1921; Sunderland, 1943; Abrams et al., 1992, 1997; Low et al., 1994). In Sunderland's (1943) study, large variations were noted between the left and right limbs for the measurement from the lateral humeral epicondyle to the bifurcation (median difference = 18.0 mm; p = 0.016) but not for the measurement from the bifurcation to the radial tunnel (median difference = 7.0 mm; p = 0.396). In conclusion, the location of the radial nerve bifurcation is subject to both intra- and inter-individual variations. Its specific relationship to the lateral humeral epicondyle also varies, occurring both distal and proximal to the level of the epicondyle. Clinical implications of these findings warrant further investigation.

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membranous in 68% and tendinous in 32% of cadavers, with minimal variation between arms from the same cadaver (Thomas et al., 2000). Exiting the radial tunnel, the posterior interosseous nerve travels deep to the extensor muscles in the forearm. All these areas have been linked with the development of radial neuropathies (Riffaud et al., 1999). Various studies have investigated the length of the posterior interosseous nerve from its bifurcation to where it enters the radial tunnel (Abrams et al., 1997; Ozturk et al., 2005). These studies found differences between individuals; however, no studies have investigated if the length varies within individuals. Differences within individuals may lead to differences in tension, and the relationship of tension and nerve blood flow has been well documented (Ogata and Naito, 1986; Clark et al., 1992). These observations have been further supported by the work of Lundborg and Rydevik (1973) and Wall et al. (1992), who found nerve conduction to be adversely affected by increasing nerve strain.

As clinicians may use the contralateral limb as a comparison during orthopedic physical examination, in neurodynamic testing; and as part of their subsequent clinical reasoning (Butler, 1996; Magee, 2005), it would be informative to establish if there is a difference between limbs in areas of tension, such as a bifurcation. This study therefore investigates if there are intra-individual differences in both the location of the radial nerve bifurcation and the length of the posterior interosseous nerve, from the bifurcation to the point at which it enters the radial tunnel.

2. Materials and methods

This study was approved by Keele University ethics committee. A convenience sample of embalmed human cadavers was tested, with expertise at postgraduate level in anatomy. The protocol — which was within the remit of the UK Human Tissue Act (2004) for anatomical examination, research and training — was piloted on one of the cadavers not subsequently used in the study. All cadavers were placed supine and in the anatomical position. The aim was for full supination, to reduce variation between limbs in the position of the posterior interosseous nerve (Lawton et al., 2007), and neutral elbow flexion and extension (i.e. 0° flexion, with no hyperextension). This position was determined by noting the long axes of the humerus and the ulna (Magee, 2005). Such standardization was to account for any right-left differences in the end range of extension or the carrying angle (Standing, 2008). Where this ideal position was not possible, due to the stiffness of the cadaver, the forearm position was matched by placing the more mobile limb identically to the less mobile limb. Each limb was dissected from the mid-humeral region to the mid forearm as directed in the protocol. In summary, the skin and subcutaneous tissues were removed from each specimen, and the LHE, radial nerve bifurcation, radial nerve branches, radial tunnel including arcade of Frohse, supinator muscle, and surrounding structures were carefully identified and left in situ. The radial tunnel structures were identified by one expert researcher and checked by another. It was considered important to exclude any specimens that could not be matched for position or had incurred disruptions during dissection. Six limbs from four cadavers had minor unilateral disruptions to the radial nerve, the posterior interosseous nerve or the radial tunnel during dissection, and these four cadavers were excluded from the study.

Therefore, 36 upper limbs from 18 cadavers (7 female), with a median age of 76.11 years (range 53–96 years), were suitable for measurement.

Measurement 1 was taken on the radial nerve between two points: where the nerve crossed a line joining the most prominent bony points of the medial and lateral humeral epicondyles and where the nerve bifurcated to form the posterior interosseous nerve. If the bifurcation occurred distal to the line joining the epicondyles, this gave a positive measurement, whereas if the bifurcation occurred proximal to this line a negative measurement was recorded (accordingly, bifurcation occurring on this line produced a measurement of zero).

Measurement 2 was taken on the posterior interosseous nerve, from the radial nerve bifurcation to the proximal edge of the supinator muscle, after which point the nerve travels deep through the radial tunnel.

The measurements were taken using analog calipers to the nearest millimeter (mm) from the left and right upper limbs of each specimen. The measurements were carried out twice on separate occasions, at least 2 h apart to minimize the possibility of the previous measurement influencing the second measurement. The measurements by the calipers were set up by one of the investigators, and read by a second investigator in order to maintain blinding of the results during the measurements. A pilot study had revealed the two measurements to vary by no more than 1 mm; this was deemed an acceptable level of agreement. The mean of the two measurements was recorded and used for data analysis.

Following dissection and measurement in situ, whole radial nerves and major branches were removed and photographed to depict more clearly left:right differences in individual cadavers (Fig. 2).

3. Data analysis

The distances from the level of the LHE to the radial nerve bifurcation (measurement 1) and from the bifurcation to the radial tunnel (measurement 2) were analyzed for both the left and right upper limbs. Differences between the left and right limbs were calculated. In the case of measurement 2, the differences had a bimodal distribution; hence non-parametric analysis was...
undertaken. The data were summarized as medians, and in order to determine whether the medians differed significantly between left and right, a Wilcoxon signed-ranks test was performed. In addition, 95% confidence intervals (CIs) were computed for the median difference, using the Wilcoxon method. Comparisons between males and females of the median left-right differences in the two measurements were performed using the Wilcoxon rank sum test. To assess the degree of interdependence of the two measurements, a Pearson correlation coefficient was calculated. Statistical significance was set at \( p \leq 0.05 \) (two-tailed).

4. Results

An example of the radial nerve dissection close to the cubital fossa is shown in Fig. 1, in this case showing a unique branching arrangement of the anomalous middle branch. Fig. 2 shows clear intra-individual variation, both along the entire radial nerve and at its terminal branching.

The raw data and summary measures for both measurements within the eighteen cadavers are shown in Table 1. The data show that all cadavers had some degree of variation in both measures between the left and right limbs.

### 4.1. Distances from the lateral humeral epicondyle line to the radial nerve bifurcation (measurement 1)

The measurements of the distance from the level of the LHE to the radial nerve bifurcation show the location of bifurcation of the radial nerve, relative to the LHE, was on average more distal in the right limbs (Table 1). The median difference of 18.0 mm (95% CI 4.5 mm, 31.0 mm) between the measurements in the left and right upper limbs for measurement 1 was statistically significant \( z = 2.418; n = 18; p = 0.016 \).

When the data across left and right limbs were pooled and each limb was taken as a single specimen, in the thirty-six radial nerves measured, the point of bifurcation was noted to vary considerably away from the level of the LHE. In ten limbs (7 left) the bifurcation occurred proximal to the LHE (measurements < 0 mm), four nerves (3 left) bifurcated level with the LHE (measurements = 0 mm) and twenty two (8 left) bifurcated distal to the LHE (measurements > 0 mm).

### 4.2. Distances from the radial nerve bifurcation to the radial tunnel (measurement 2)

The median difference between left and right for the distance from the radial nerve bifurcation to the radial tunnel was, at 7.0 mm.

### Table 1

<table>
<thead>
<tr>
<th>Sex (age)</th>
<th>Measurement 1: lateral epicondyle to radial nerve bifurcation (mm)</th>
<th>Measurement 2: radial nerve bifurcation to radial tunnel (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (74)</td>
<td>50.0 40.0</td>
<td>Female (85)</td>
</tr>
<tr>
<td>Male (96)</td>
<td>16.0 57.0</td>
<td>Female (64)</td>
</tr>
<tr>
<td>Male (80)</td>
<td>12.0 19.0</td>
<td>Male (38)</td>
</tr>
<tr>
<td>Female (86)</td>
<td>11.0 12.0</td>
<td>Male (82)</td>
</tr>
<tr>
<td>Male (76)</td>
<td>12.0 36.0</td>
<td>Female (79)</td>
</tr>
<tr>
<td>Male (79)</td>
<td>17.0 37.0</td>
<td>Female (73)</td>
</tr>
<tr>
<td>Male (66)</td>
<td>21.0 30.0</td>
<td>Female (82)</td>
</tr>
<tr>
<td>Female (79)</td>
<td>10.0 44.0</td>
<td>Female (77)</td>
</tr>
<tr>
<td>Male (78)</td>
<td>20.0 52.0</td>
<td>Male (53)</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>7.0 36.0</td>
<td>Male (74)</td>
</tr>
<tr>
<td>Male (82)</td>
<td>24.0 31.0</td>
<td>Female (82)</td>
</tr>
<tr>
<td>Female (77)</td>
<td>1.0 28.0</td>
<td>Male (82)</td>
</tr>
<tr>
<td>Male (78)</td>
<td>20.0 25.0</td>
<td>Male (53)</td>
</tr>
<tr>
<td>Median difference (95% CI)</td>
<td>18.0 (4.5, 31.0)</td>
<td>Median difference (95% CI)</td>
</tr>
</tbody>
</table>

(95% CI = 10.5 mm, 18.5 mm), smaller than that for measurement 1 (Table 1). Whilst the median distance was slightly longer in the left upper limbs, the difference between left and right limbs was not statistically significant \( z = 0.850; n = 18; p = 0.396 \).

4.3. Correlation of the measurements

The Pearson correlation between measurement 1 and measurement 2 was \( r = 0.790 \) \((p = 0.001)\) for the left limbs and \( r = 0.471 \) \((p = 0.049)\) for the right limbs, indicating that the two measurements tend to be inversely related.

4.4. Male/female comparisons

The median left-right differences for males and females in measurement 1 were 31 mm and 16 mm respectively; this difference was statistically significant \( W = 43.5; n_1 = 11, n_2 = 7; p = 0.037 \). The median left-right differences for males and females in measurement 2 were 27 mm and 20 mm respectively; this difference was not significant \( W = 50.5; n_1 = 11, n_2 = 7; p = 0.147 \).

5. Discussion

This study found a difference of between 1 mm and 73 mm in the length of the radial nerve from the LHE to the radial nerve bifurcation (measurement 1) between left and right limbs, in all eighteen cadavers. This was found to be statistically significant \( p = 0.016 \). These findings support Sunderland’s (1943) initial observation and illustrate that the morphology of the radial nerve is not bilaterally symmetrical and is subject to intra-individual variation, with an estimated median difference of 18 mm in the location of the radial nerve bifurcation. Sunderland (1943) noted some variation in the branching of nerves between limbs from the same...
specimen, but this was not measured in his study. Previous literature drawing inter-individual comparisons (Linell, 1921; Sunderland, 1943; Abrams et al., 1992, 1997) has concluded that the bifurcation point of the radial nerve is variable. Our study confirmed not only differences between individuals but also a significant difference within individuals.

Wright et al. (2005) observed the excursion of the radial nerve during neurodynamic testing (Butler, 1996). They noted that the total excursion of the radial nerve during extreme upper limb movements was typically 14.2 mm. This measurement was taken at 4–6 cm proximal to the LHE. In our study, the median distance between the right and left limb measurement was 18 mm. For most of the cadavers this within individual variation was larger than the amount of excursion observed by Wright et al. (2005). This may support the view that the commonly used neurodynamic test may place different stresses on left and right radial nerves. The relationship between nerve tension, nerve blood flow and nerve conduction has been well documented (Lundborg and Rydevik, 1973; Ogata and Naito, 1986; Clark et al., 1992; Wall et al., 1992).

Sunderland (1978) proposed that at the point where a nerve branches it is often attached to the surrounding tissue. It could be suggested that the tissue response at this point of the nerve may be asymmetrical, especially if the difference between the left and right limbs is of sufficient magnitude. In our study the greatest difference noted between contralateral limbs was 73 mm.

It is possible that the difference in location of the radial nerve bifurcation is of clinical importance when the nerve glides near to a bony prominence. We noted that in some specimens, the bifurcation of the radial nerve was proximal to the LHE in one limb and distal to the LHE in the contralateral limb; this occurred in eight cadavers. Subjective observations also indicated that the size and shape of the bony LHE also varies between limbs of the same cadaver, but this was not measured.

Our observation that a majority of the nerves bifurcated more distally in the right limb than in the left could be related to handedness. Data indicating the handedness of our specimens was not, however, available. Also, the older age of the cadavers available for this study (range 53–96 years) suggests there had been time for nervous tissue adaptation during the individuals’ lifespan. Chakravarthy Marx et al. (2009) found that there is an increase in total nerve cross-sectional area of the radial nerve in elderly cadavers. It could be argued that due to handedness, bilateral anatomical variations may be the consequence, and not the cause, of asymmetrical forces placed on nerve tissue. This could usefully be investigated in future studies.

When combining the left and right data and treating each measurement as a single specimen, the location of the bifurcation of the radial nerve was noted to be more variable than in previous studies (Linell, 1921; Sunderland, 1943; Abrams et al., 1992, 1997), with a range in bifurcation point of 107 mm (from −50 mm to 57 mm). Using the LHE as a reference point, we found that twenty-two nerves bifurcated distal to the LHE, ten proximal to the LHE, and four at the level of the LHE. These findings support Linell (1921), Sunderland (1943), Abrams et al. (1992) and Low et al. (1994), who all reported that the majority of nerves bifurcate distal to the LHE. However, we found bifurcations that were more distal and more proximal than those in previous reports.

In contrast to the above, intra-individual differences in the length of the posterior interosseous nerve from the bifurcation to the radial tunnel (measurement 2), with a median of 7 mm, were found to be non-significant (p = 0.396). Nonetheless, none of the cadavers tested demonstrated identical measurements between left and right.

When differences were compared between males and females, the differences between left and right for measurement 1 were more pronounced for males. It would be advisable to confirm this finding in a larger study. Nonetheless, it may be wise to exercise caution when making comparisons with the contralateral limb during the examination of male patients.

As would be expected of measurements taken on a single structure within a defined anatomical area, there was evidence of interdependence of the two measurements, as demonstrated by the negative correlation between them; i.e. if measurement 1 is large, measurement 2 will tend to be correspondingly small, and vice versa. This correlation on the right approached, and on the left surpassed, a ‘large’ magnitude of 0.50 (Cohen, 1988).

It could be argued that variables such as age, gender and tissue changes, incurred during embalming of the cadavers, should be taken into consideration. However because we were looking at intra-individual differences, where such factors are likely to be constant within a given cadaver, we considered these issues would only have a minor effect on the measurements. The carrying angle for males and females differs (Standing, 2008) and the embalmed limbs are stiffer than in vivo; this was addressed in our study by placing all the elbows in, as near as possible, identical neutral flexion and extension to standardize the right and left limbs. If there was any doubt, the cadavers were excluded from the study.

The CIs for the intra-individual differences in the nervous structures are somewhat wide. However, the sample size of this study was dictated by the availability of cadavers; replication of our study in a larger sample would provide more precise estimates and more detailed information on the distribution of these measurements.

The results of this study have demonstrated that the location of the bifurcation of the radial nerve is variable both within and between individuals; how these variations affect nerve tissue during upper limb movements cannot, however, be determined. Further in vivo investigations are needed, such as non-invasive imaging techniques. High specification equipment may permit observation of the movement of the nerve, and how it glides over other tissues (Bargallo et al., 2010). If both asymptomatic and symptomatic patients were to be investigated, it should be possible to indicate whether these anatomical differences are because of, or predispose to, nervous tissue pathology.

6. Conclusion

We found the location of the bifurcation of the radial nerve is subject to both intra- and inter-individual variations. The bifurcation point was found to be extremely variable, with bifurcations occurring more proximal and more distal to the level of the LHE than commonly reported in previous literature. The clinical implications, such as the development of pathological changes in the radial nerve, cannot be determined from this study, but warrant further investigation.

References


