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Reference values for the cross-sectional area of normal radial nerve at two levels using high-resolution ultrasonography

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radial nerve, high resolution ultrasonography, ultrasound, cross-sectional area, peripheral nerves

Abstract

Aim of the study: High-resolution ultrasound is less often used to evaluate the radial nerves. The radial nerve is often involved in entrapment syndromes. The aim of the study is to establish the reference values for the cross-sectional area of the normal radial nerve on high-resolution ultrasonography, and to identify relationships between the cross-sectional area and the subject's age, gender, height, weight, body mass index, and hand dominance. **Material and methods:** The study was conducted on 200 subjects of both sexes, between 18 and 75 years of age, who did not have history of peripheral neuropathy or trauma to the upper limb. High-resolution real-time sonographic examination of the radial nerves was performed in both arms at two different levels. Level 1 was taken just proximal to the nerve bifurcation, and level 2 just after the nerve exits the spiral grove. **Results:** The mean cross-sectional area measured at level 2 (4.3 ± 0.4 mm^2) was greater than that measured at level 1 (2.3 ± 0.3 mm^2). No significant relationship was seen with age and hand dominance (p >0.05), but the cross-sectional area values at above mentioned levels were larger in males than in females (p <0.05). In addition, the cross-sectional areas of the radial nerves showed a positive correlation with height, weight, and body mass index (p <0.05). **Conclusion:** The established ultrasonographic reference values along with basic clinical data will aid in the diagnosis, response to treatment, and prognostic evaluation of peripheral neuropathies.

Introduction

Clinical and electrodiagnostic evaluations of peripheral nerves are widely used nowadays to assess the severity of trauma to the peripheral nerves. However, a major limitation is that these approaches are not able to determine the extent of damage to the nerve fibers in the first 6 weeks post trauma[1]. Another disadvantage is that CT and MRI scans for neurographic studies are not always readily available and prove to be costly. High-resolution ultrasonography, on the other hand, is a dynamic, portable and cost-effective modality for the assessment of the peripheral nerves.

On ultrasound, the peripheral nerves show a tape-like fibrillar pattern on longitudinal scans and an ovoid fibrillar pattern on transverse scans. These specific patterns with a characteristic echotexture on sonography can be well correlated with the normal histology of the nerves[2].

The radial nerve is more commonly involved in entrapment syndromes compared to other peripheral nerves of the upper limb, such as the median or ulnar nerve. Common sites of nerve entrapment are the junction of the middle and distal third of the arm (post traumatic), just distal to the elbow (arcade of Frohse), and proximal to the wrist between the brachioradialis and the extensor carpi radialis longus[3]. Generally, it is difficult to diagnose the condition clinically, and the final diagnosis is mostly obtained by excluding other differentials. This can lead to a delay in the initiation of effective treatment[3].

Studies show that high-resolution ultrasonography is useful for the localization of trauma, entrapment neuropathies, and infectious conditions and neoplasms involving the peripheral nerves[4–6].

The present study seeks to obtain high-resolution sonographic images of normal radial nerves to assess potential

Fig. 1. *High-resolution ultrasonography of the radial nerve of the right upper limb done with the patient in supine position using a high-resolution linear transducer (5–18 MHz) at the level of the elbow just proximal to its bifurcation into the superficial sensory nerve and posterior interosseous nerve (level 1)*

relationships between the CSA and the age, gender, height, weight, body mass index (BMI), and hand dominance of the subjects.

Material and methods

The study was conducted on 200 subjects. Individuals of both sexes, between 18 and 75 years of age, not having any history of peripheral neuropathy or trauma to the upper limb, and referred to the department of radiodiagnosis and imaging of the Sri Guru Ram Das Institute of Medical Sciences and Research, Sri Amritsar, for other medical or surgical conditions, were included in the study. Ethical clearance for the study was granted by the ethics committee at the Sri Guru Ram Das Institute of Medical Sciences and Research (reference number: Patho190/19).

Patients showing features of peripheral neuropathy as a result of trauma, pregnancy, diabetes mellitus, hypothyroidism or alcoholism were excluded from the study. After obtaining informed written consent from each subject, detailed clinical history was recorded, and high-resolution ultrasonography of the radial nerve was performed in both arms.

Ultrasonography technique

High-resolution sonography was performed using Philips Affiniti 50 ultrasound unit with a linear transducer having a frequency range of 5–18 Mhz. The depth, gain, and dynamic range were adjusted for better characterization between the radial nerve and adjacent soft tissues. The sonographic images were obtained with the subject in supine position. The sonographic images were recorded by placing the transducer probe perpendicular to the normal radial nerve. The reference values for the CSA of the nerve at two levels were measured by the ultrasonographer in 200 subjects. At each level, the CSA of the radial nerve was calculated by circumferentially tracing the inner side of the peripheral hyperechoic rim of the nerve. The pressure of the transducer on the skin was kept to a minimum to reduce as far as possible the deformation of the underlying structures. A few studies have demonstrated the use of standard imaging as well as write-zoom magnification methods for measurement of the CSA. In the present study, we used only standard imaging.

The CSA were measured in the following locations: the radial nerve 2 cm proximal to its bifurcation into the superficial sensory nerve and the posterior interosseous nerve (level 1) (Fig. 1, Fig. 2), and the radial nerve in the anterior compartment just after it exits the spiral groove (level 2) (Fig. 3, Fig. 4).The CSA value was measured three times at the same level, and the mean was then calculated at each level (Fig. 5, Fig. 6, Fig. 7, Fig. 8, Fig. 9, Fig. 10, Fig. 11, Fig. 12). Age, gender, height, weight body mass index and hand dominance obtained from each subject were documented. The correlation coefficients were calculated by statistically correlating these parameters with the cross-sectional area of the radial nerve at both levels.

Statistical analysis

The data was analyzed using SPSS 24.0 software. Qualitative variables (sex, hand dominance) as well as quantitative variables (CSA, BMI, age, height, weight) were evaluated in the study. The means as well as standard deviations for the CSA of the radial nerves were calculated at two levels in bilateral upper arms in both men and women. Independent sample t-test was used to evaluate the association between the qualitative (gender and hand dominance) and quantitative (CSA) variables. The correlation of the mean CSA of the radial nerves with age, height, weight, and body mass index (BMI) was done using Pearson's correlation analysis ('r' value). *P* values less than 0.05 were considered statistically significant.

Results

The mean CSA of the radial nerves calculated at level 1 and level were 2.3 ± 0.3 mm^2 and 4.3 ± 0.4 mm^2, respectively. There was a considerable difference in the mean CSA calculated at both these levels ($p < 0.05$) with CSA being more in the proximal part of the nerve (level 2) than the distal part (level 1) (Tab. 1).

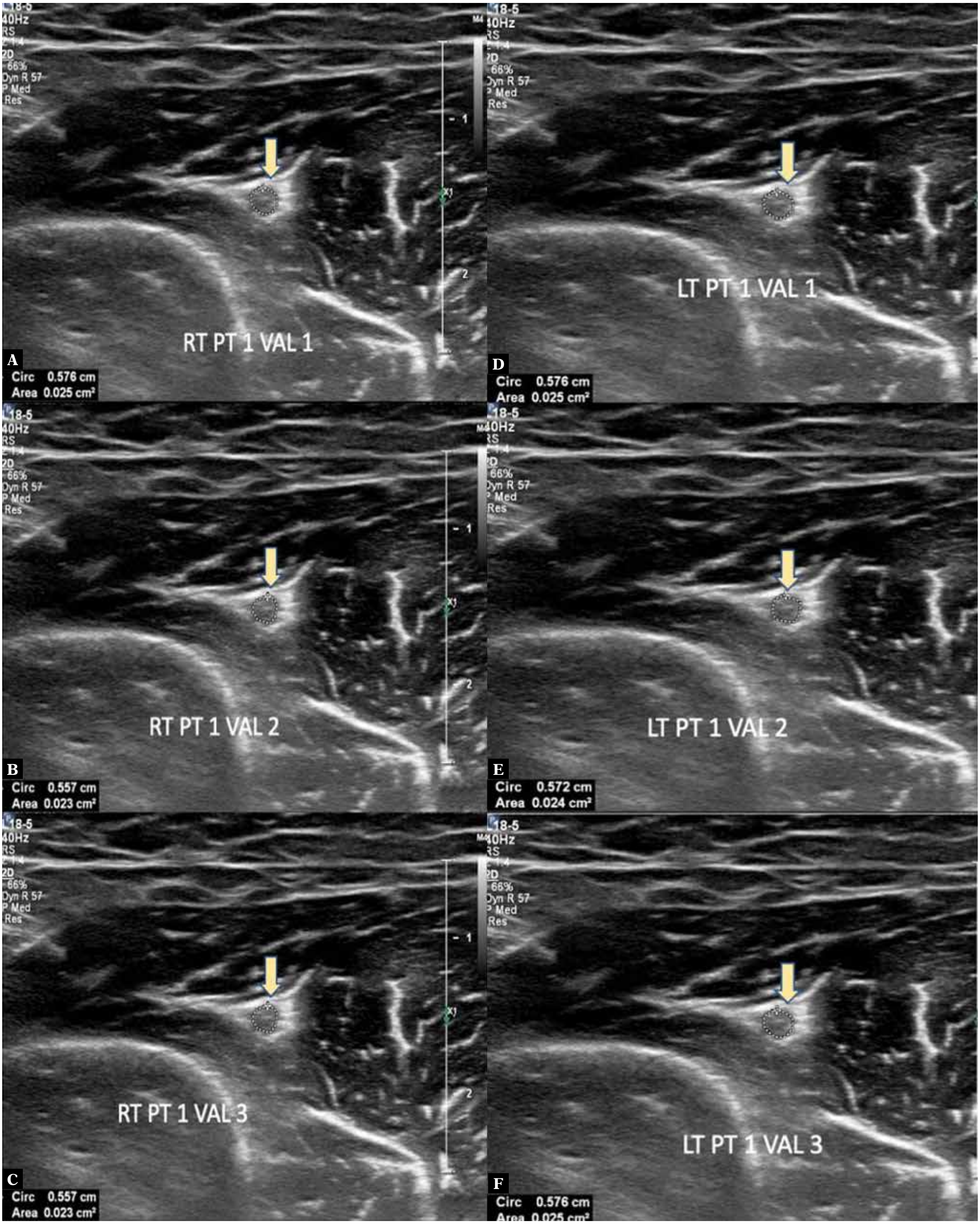

Fig. 2. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right and left upper limbs in the axial plane at level 1 in a 70-year-old male weighing 60 kg, with a height of 167 cm and a body mass index of 21.4 kg/m². The mean cross-sectional area on the right (***A, B, C***) and left (***D, E, F***) sides are 2.4 mm² and 2.5 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

Fig. 3. *High-resolution ultrasonography of the radial nerve of the right upper limb done with the patient in supine position using a high-resolution linear transducer (5–18 MHz) at the anterolateral aspect of the mid-humerus just after it exits the spiral groove (level 2)*

Tab. 1. *Mean cross-sectional area (cm2) of the radial nerves at levels 1 and 2*

Level	CSA	
	Mean	SD
Level 1	0.023	0.003
Level 2	0.043	0.004
***p*-value**	0.001	
CSA – cross-sectional area, SD – standard deviation		

Men had a significantly larger mean CSA than women ($p = 0.001$) at both levels in bilateral arms. (Tab. 2). No significant statistical difference ($p > 0.05$) was observed in the mean CSA of the radial nerves on comparison of the dominant and non-dominant arms (Tab. 3).

The mean CSA of the radial nerves at both levels in bilateral arms showed a significant ($p < 0.05$) positive correlation with height (Tab. 4), weight (Tab. 5) and body mass index (Tab. 6) as calculated by Pearson's correlation analysis (positive *r* value). However, a correlation was observed between the mean CSA of the radial nerves and the age of the subjects ($p < 0.05$) (Tab. 7).

Discussion

High-resolution ultrasonography is a newly evolving tool to evaluate disorders of the peripheral nervous system[7]. The ultrasound appearance of a normal peripheral nerve shows

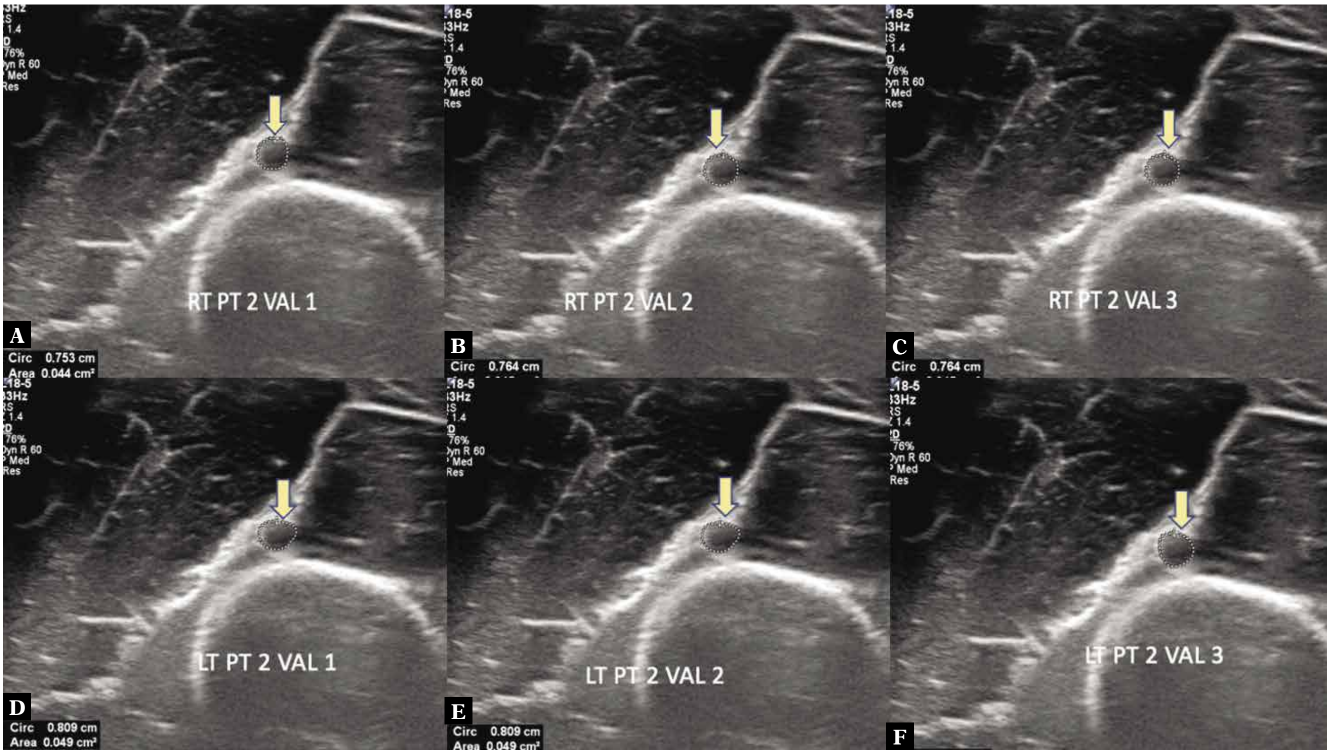

Fig. 4. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right and left upper limbs in the axial plane at level 2 in a 70-year-old male weighing 60 kg, with a height of 167 cm and a body mass index of 21.4 kg/m². The mean cross-sectional area on the right (**A**, **B**, **C**) and left (**D**, **E**, **F**) sides are 4.5 mm² and 4.8 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

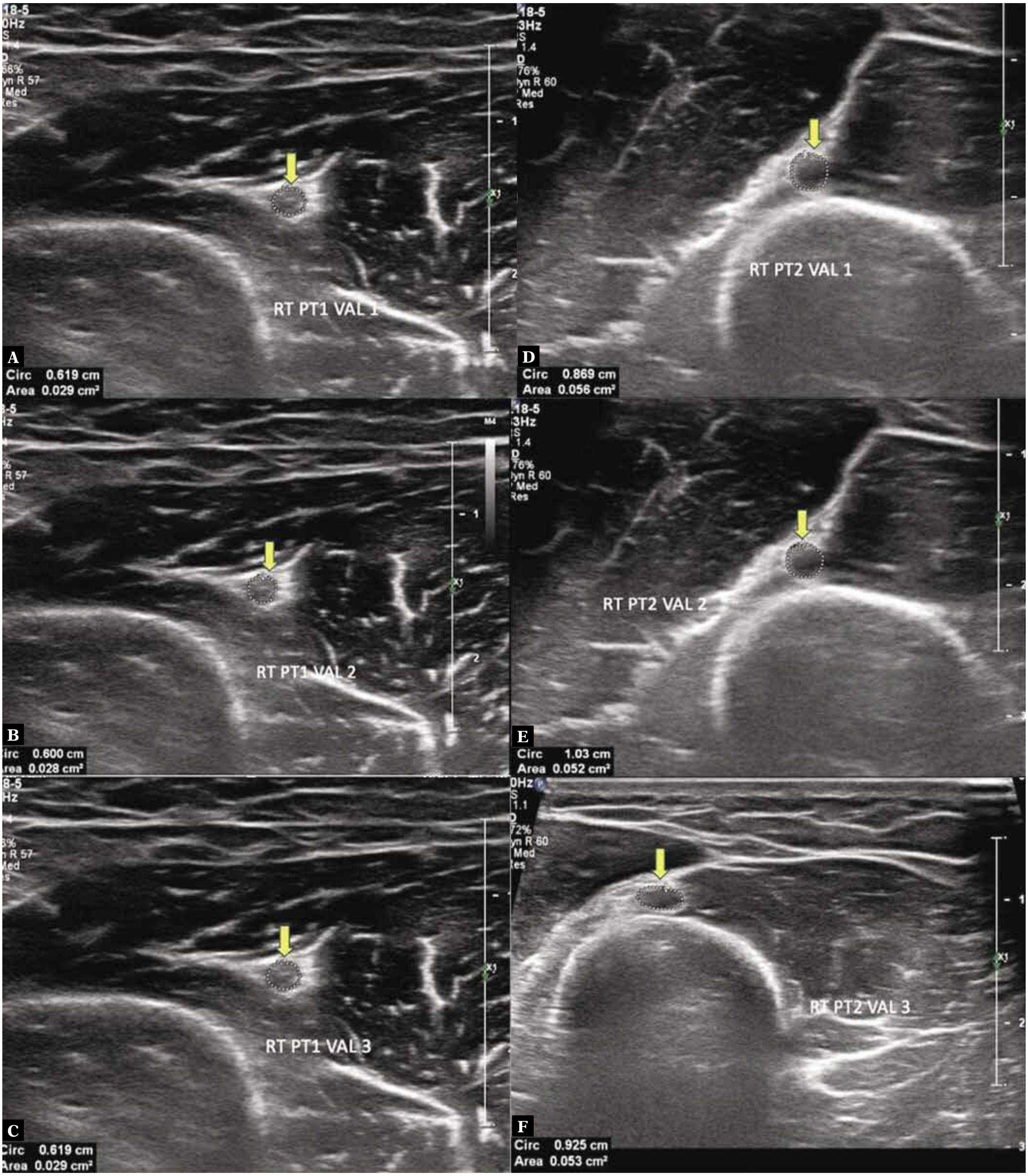

Fig. 5. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 63-year-old female weighing 87 kg, with a height of 162 cm and a body mass index of 33.2 kg/m². The mean cross-sectional areas at level 1 and level 2 are 2.9 mm² and 5.4 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

multiple hypoechoic longitudinal nerve fascicles which are separated by discontinuous echogenic bands corresponding to the epineurium[8–11]. A previous study done by Alshami *et al*. found that ultrasonography could accurately measure the CSA of the peripheral nerves[12]. In our study, a linear transducer with a frequency range of 5–18 MHz

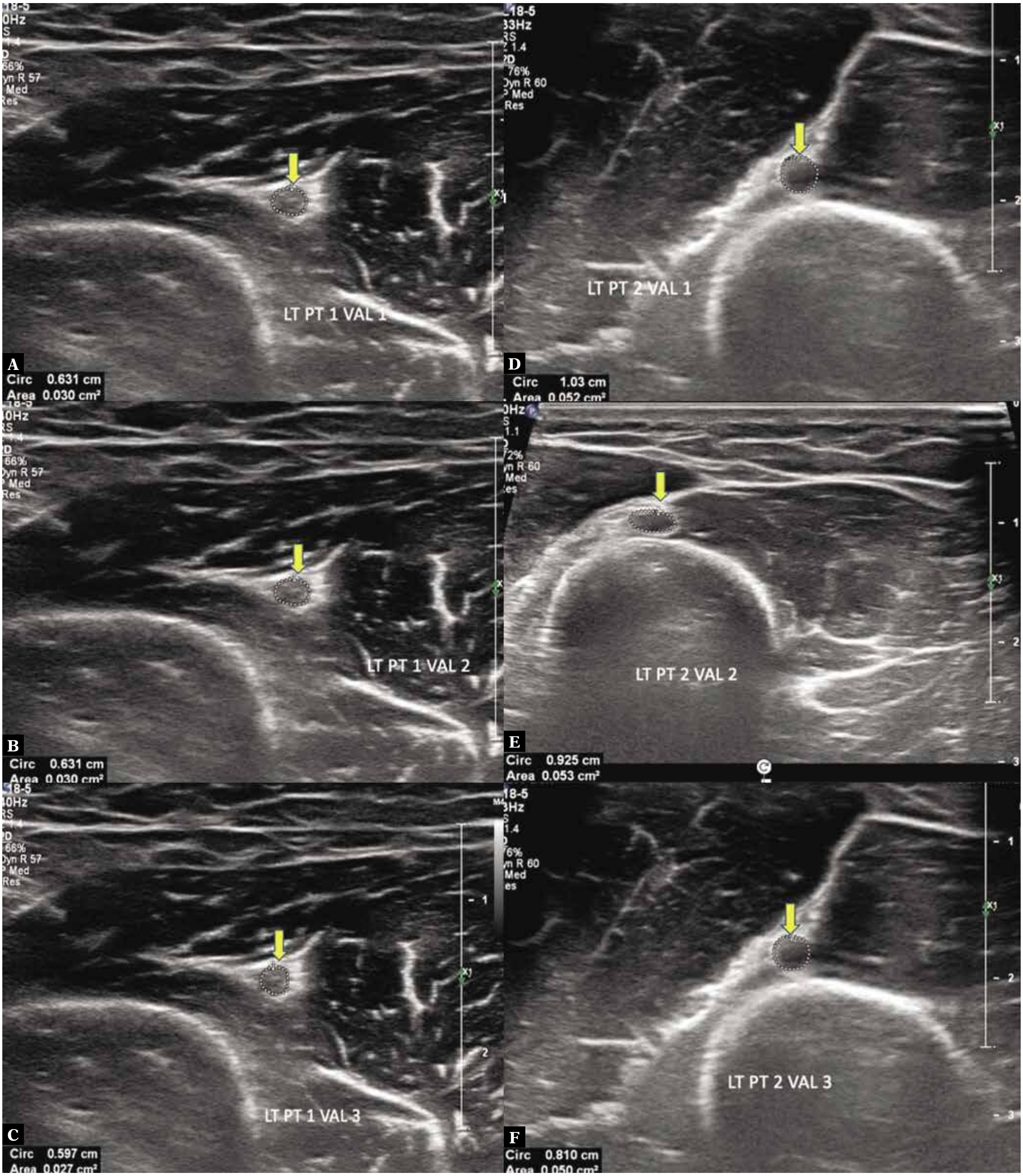

Fig. 6. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the left upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 63-year-old female weighing 87 kg, with a height of 162 cm and a body mass index of 33.2 kg/m². The mean cross-sectional areas at level 1 and level 2 are 2.9 mm² and 5.2 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

was used to scan the radial nerve of both upper arms, easily demonstrating the radial nerve fascicles. In most previous studies, the diameter instead of the CSA was used in evaluating the size of the nerve[1,12,13]. However, in recent studies, the measurement of the CSA has been advised, as it provides the precise CSA[14–16]. Some common variations

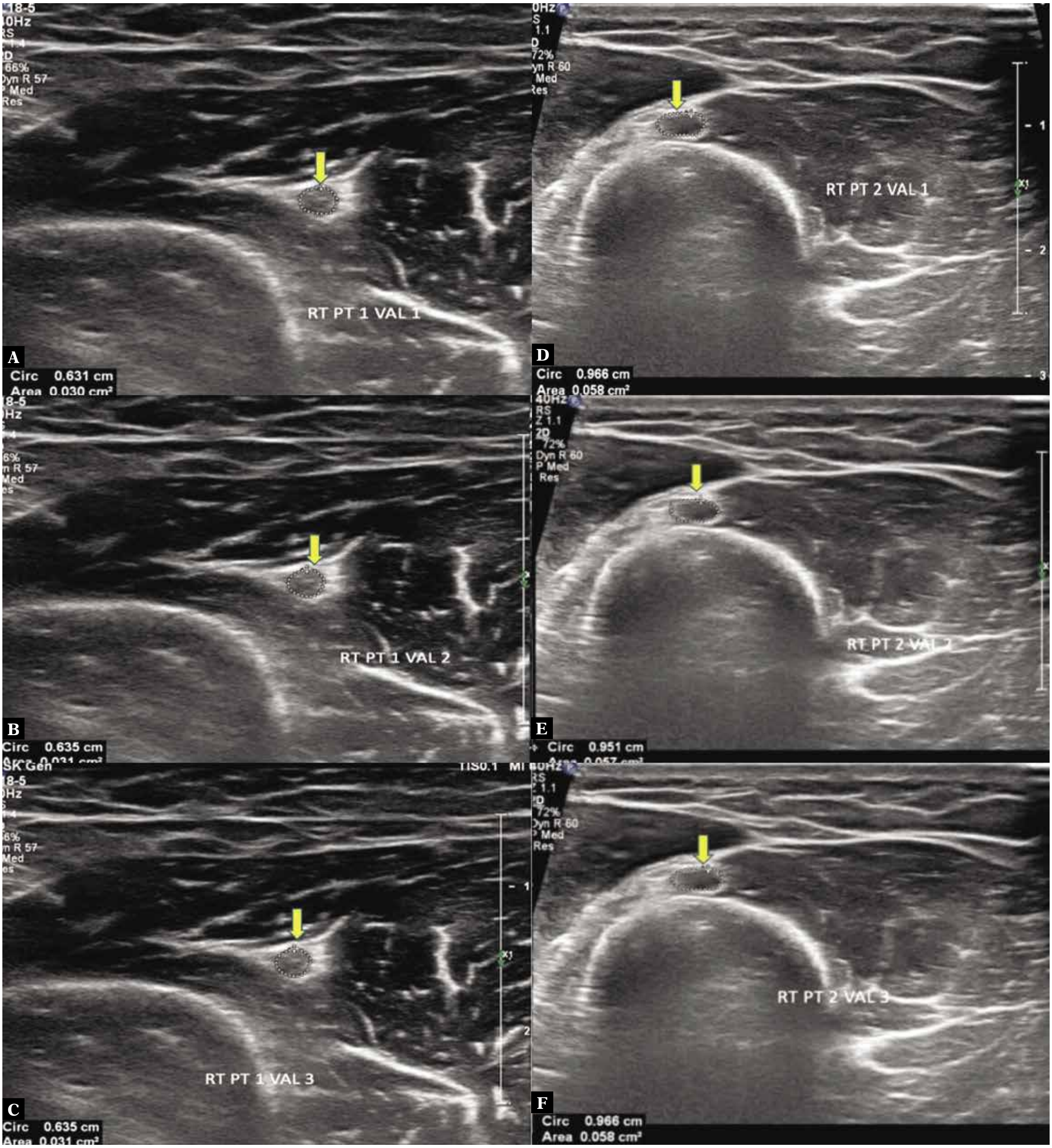

Fig. 7. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 64-year-old male weighing 83 kg, with a height of 180 cm and a body mass index of 25.6 kg/m². The mean cross-sectional areas at level 1 and level 2 are 2.9 mm² and 5.8 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

included minor alterations, such as round to oval shapes at separate locations within the arm. In our study, it may be argued that the CSA is a reliable and more consistent index than the nerve diameter because of the presence of variable shapes. We measured the mean CSA values of the radial nerves at two levels in both arms.

The mean CSA values in our present study were 2.3 ± 0.3 mm² and 4.3 ± 0.4 mm² at levels 1 and 2, respectively (Tab. 1). The CSA of the nerve varies along its course in the arm, with the nerve being thicker in the proximal part and having a greater CSA. In a study conducted by Chen *et al*., it was seen that the mean CSA of the radial nerves at

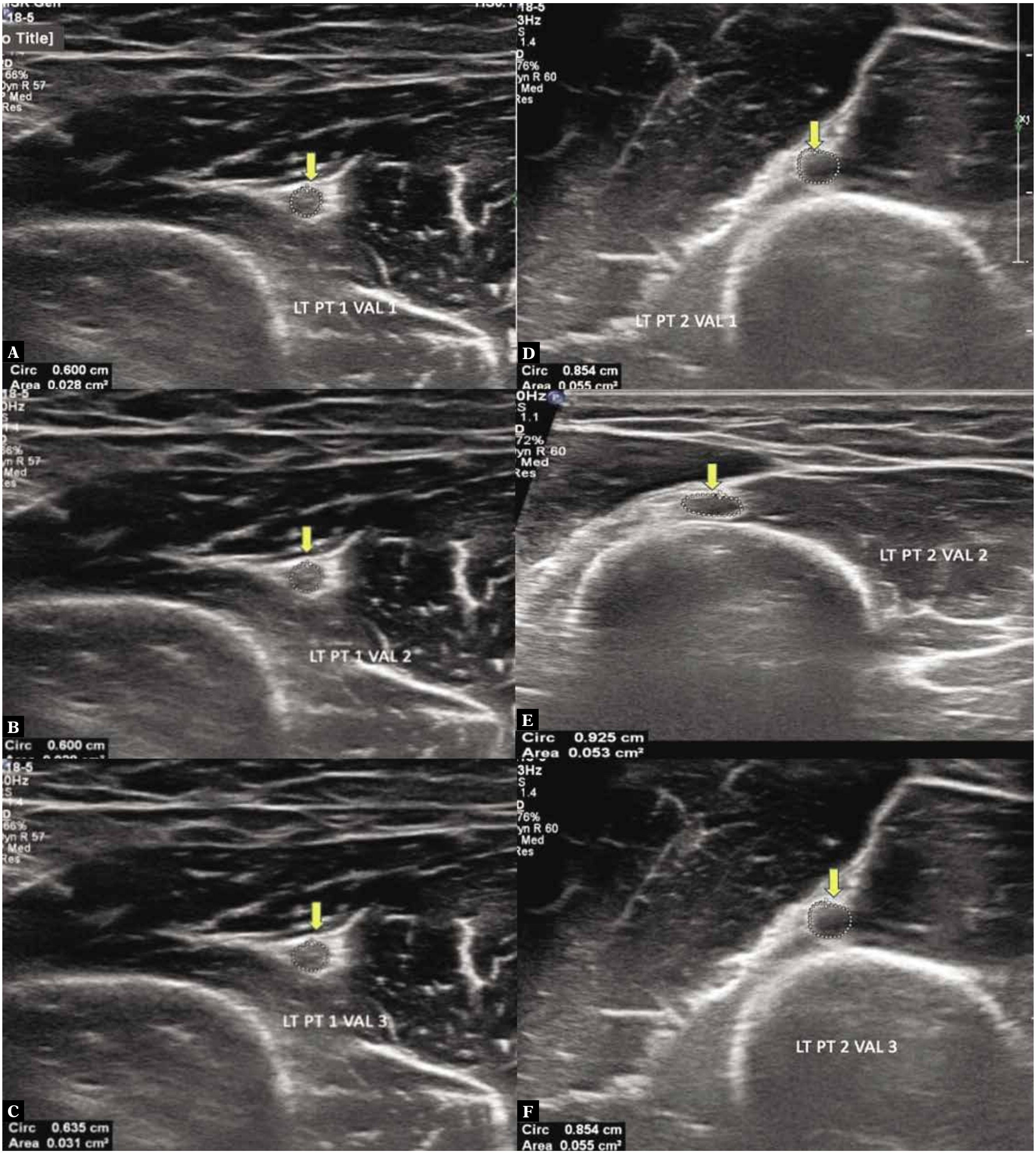

Fig. 8. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the left upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 64-year-old male weighing 83 kg, with a height of 180 cm and a body mass index of 25.6 kg/m². The mean cross-sectional areas at level 1 and level 2 are 2.9 mm² and 5.4 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

4 cm above the lateral epicondyle of the humerus and at the midpoint between the elbow crease and axilla were 5.14 ± 1.24 mm² and 5.08 ± 1.23 mm², respectively, suggesting that the mean CSA of the radial nerve was consistent throughout its entire length[(17)]. Tagliafico *et al*. in their study showed that the mean CSA values and standard deviations for the radial nerve at the humeral shaft and along the supinator muscle were 7.2 ± 2.9 mm² and 2.3 ± 1.3 mm², respectively[(18)]. Won *et al*. found that the CSA of the radial nerve at the level of the spiral groove and antecubital fossa

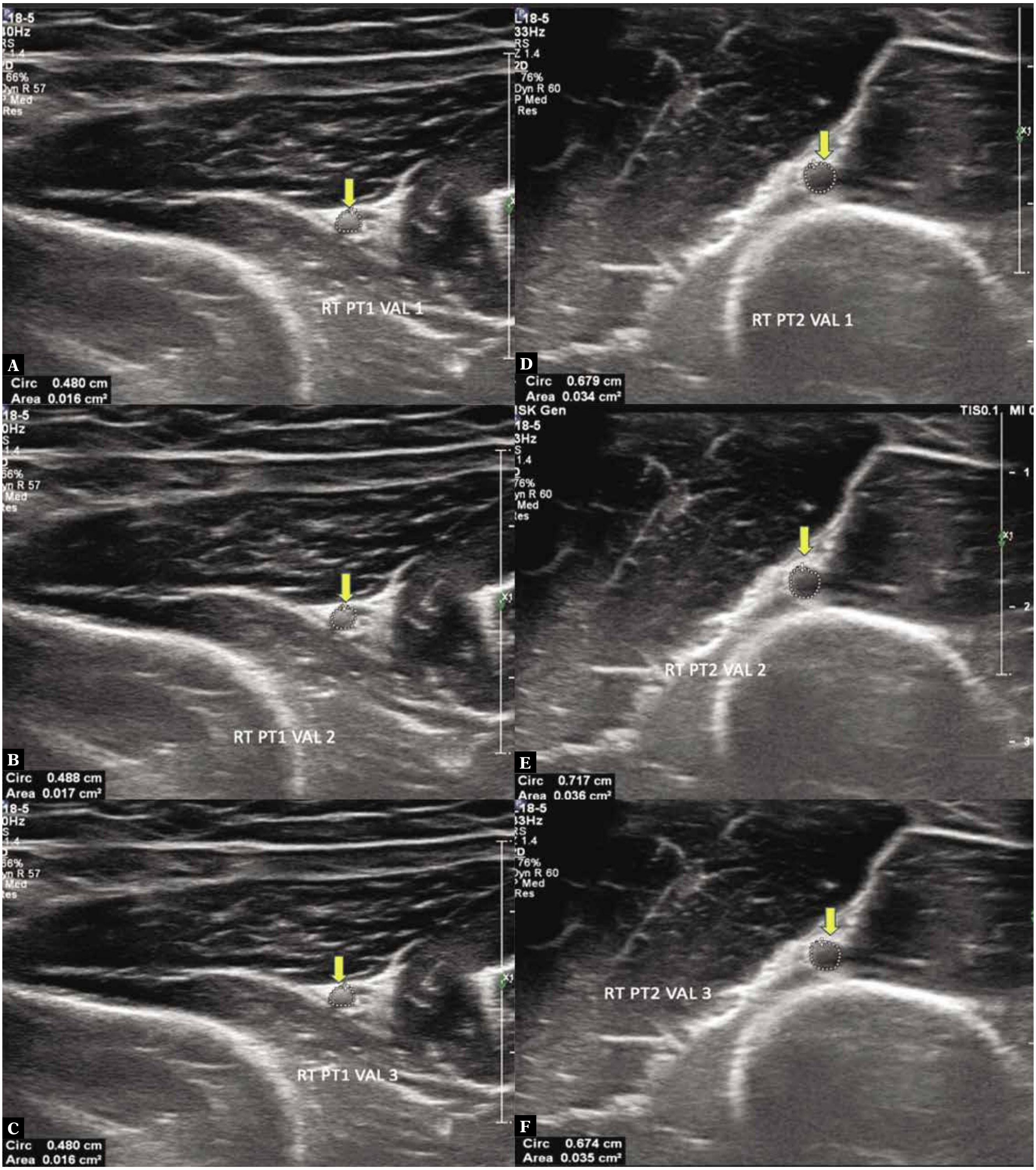

Fig. 9. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right upper limb in the axial plane at level 1 (**A, B, C**) and level 2 (**D, E, F**) in a 26-year-old female weighing 53 kg, with a height of 154 cm and a body mass index of 22.3 kg/m². The mean cross-sectional areas at level 1 and level 2 are 1.6 mm² and 3.5 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

was 4.58 ± 0.85 mm² and 4.53 ± 0.75 mm², respectively for the right arm. For the left arm, these values were 4.65 ± 0.91 mm² and 4.47 ± 0.75 mm², respectively[19]. The mean CSA of the radial nerve at the spiral groove in healthy subjects was 3.2 ± 1.5 mm² in another study conducted by Kerasnoudis *et al*.[20]. The observed variability in reference values may be due to differences in the population being studied[21,22].

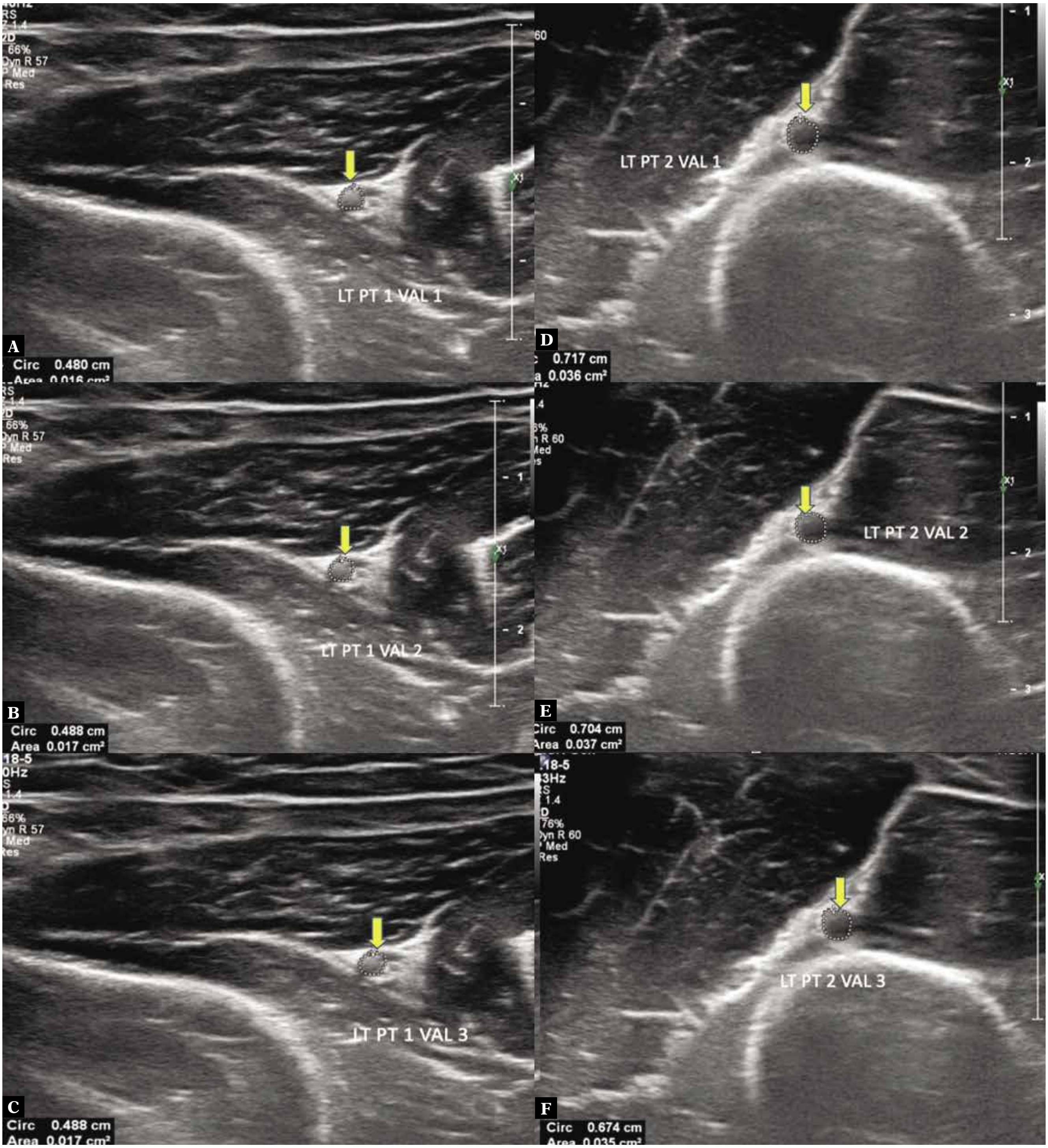

Fig. 10. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the left upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 26-year-old female weighing 53 kg, with a height of 154 cm and a body mass index of 22.3 kg/m². The mean cross-sectional areas at level 1 and level 2 are 1.7 mm² and 3.6 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left, PT – point, VAL – value)*

Bedewi *et al*. in their study showed that the CSA reference values of the upper limb nerves correlated with age, weight, and BMI. However, in that study, the CSA reference values did not correlate with height[23]. Chen *et al*. in their study found that a strong correlation existed between the CSA of the radial nerves and the height and weight of the subjects, with a correlation coefficient of 0.36 ($p < 0.05$)[17]. Tagliafico *et al*. also showed a weak correlation of the radial nerve size with height, and a relatively strong correlation with weight and body mass index[18]. In our study, the mean CSA of the bilateral radial nerves at levels 1 and 2 showed a significant ($p < 0.05$) positive

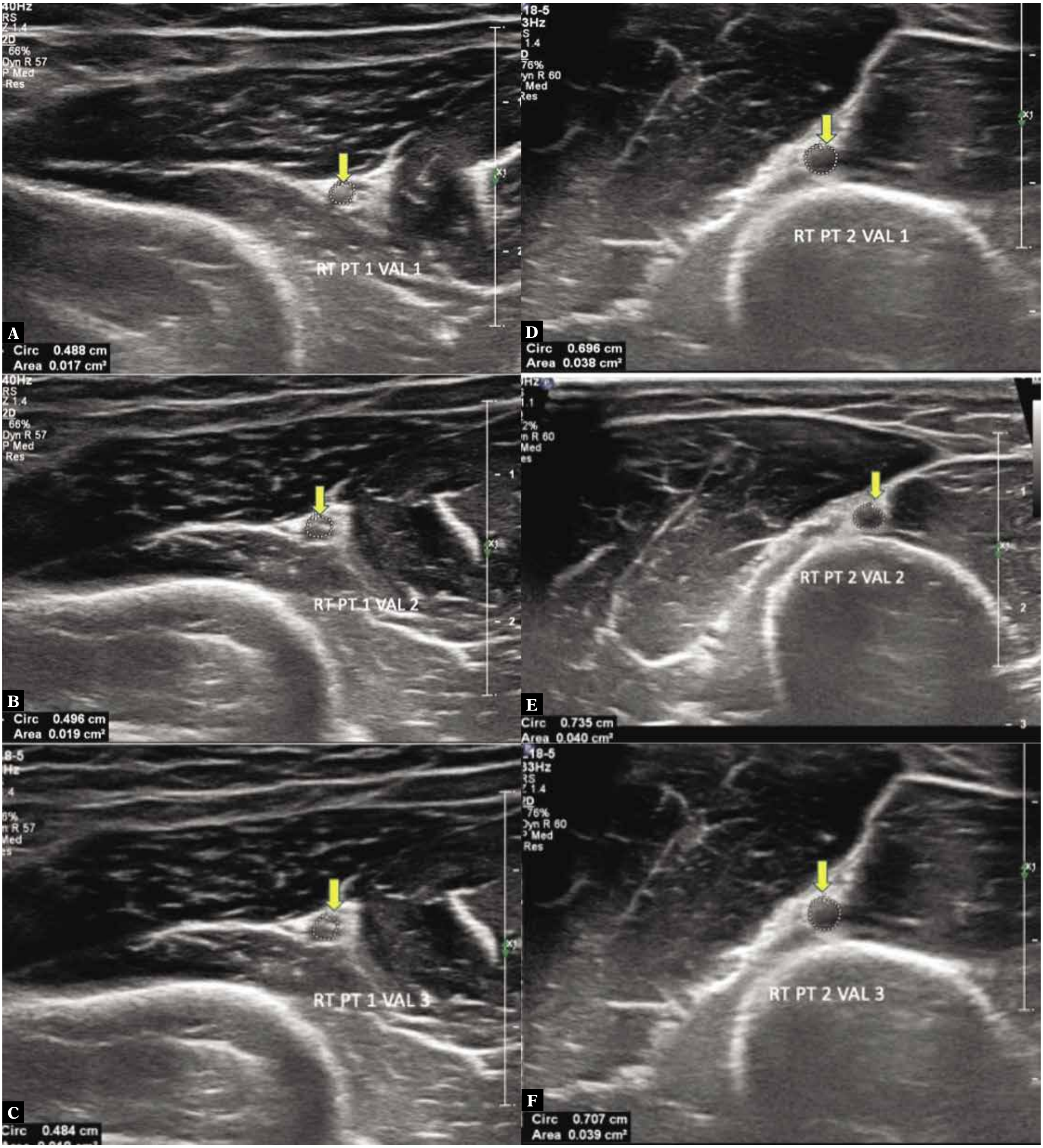

Fig. 11. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the right upper limb in the axial plane at level 1 (***A***,* **B***,* **C***) and level 2 (***D***,* **E***,* **F***) in a 21-year-old male weighing 55 kg, with a height of 154 cm and a body mass index of 23.2 kg/m*^{2}*. The mean cross-sectional areas at level 1 and level 2 are 1.7 mm*^{2} *and 3.9 mm*^{2}*, respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

correlation with height (Tab. 4), weight (Tab. 5), and body mass index (BMI) (Tab. 6).

Chen *et al*. also observed that there was no statistical significance between the CSA reference values of the radial nerves and the age of the subject. There was also no statistical difference (p >0.05) in the mean CSA values of the bilateral radial nerves when the dominant and non-dominant arms were compared (p >0.05). In addition, they proved that women had smaller mean cross-sectional areas of the radial nerve than men

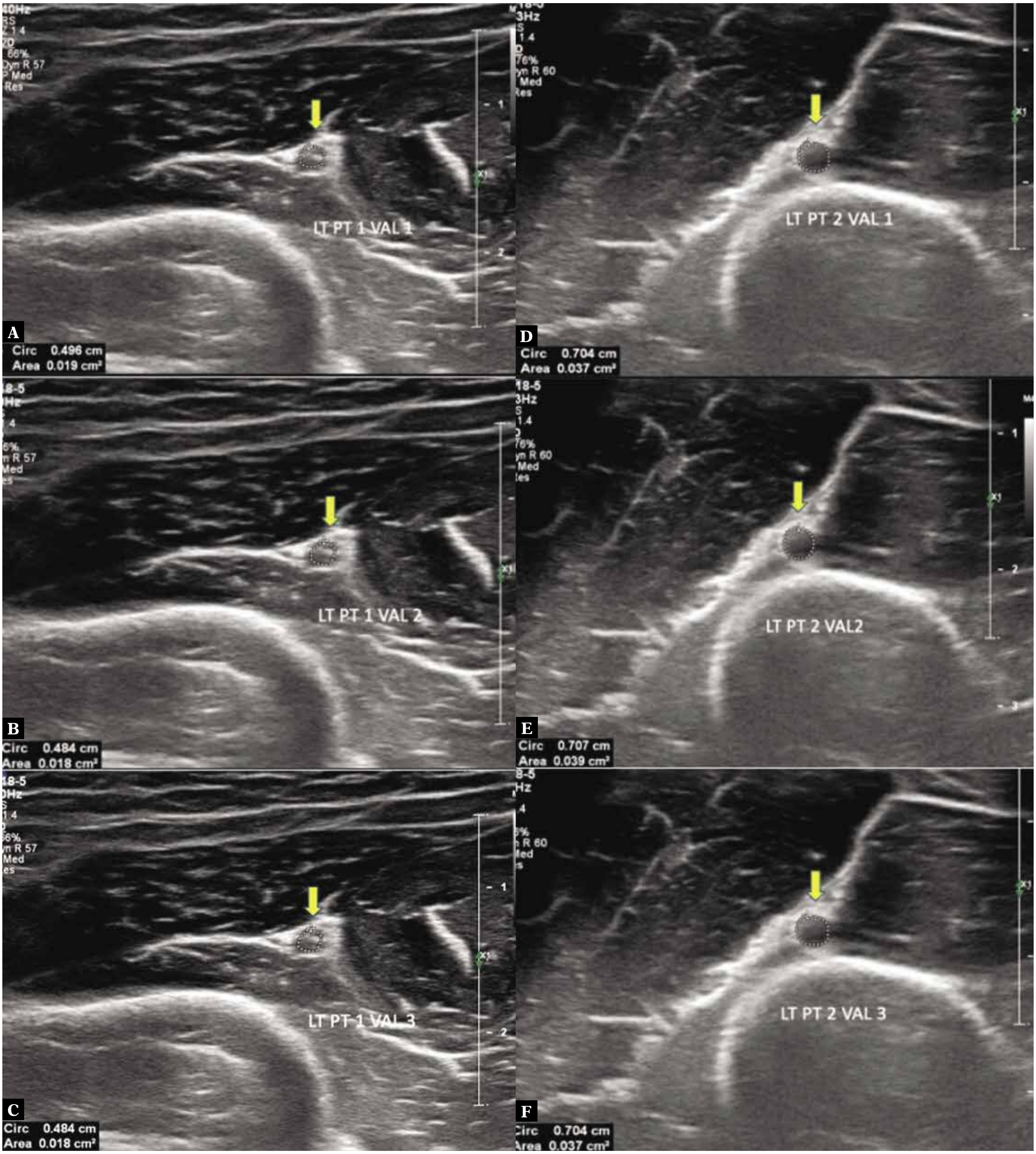

Fig. 12. *Ultrasonographic cross-sectional area values of the normal radial nerve (arrows) of the left upper limb in the axial plane at level 1 (***A, B, C***) and level 2 (***D, E, F***) in a 21-year-old male weighing 55 kg, with a height of 154 cm and a body mass index of 23.2 kg/m². The mean cross-sectional areas at level 1 and level 2 are 1.8 mm² and 3.8 mm², respectively (yellow arrow – radial nerve, RT – right, LT – left. PT – point, VAL – value)*

(p <0.05) in measurements performed at two sites[17]. However, Tagliafico *et al*. in their study showed a weak correlation of nerve size with the age of the subjects, and no correlation with the dominant and non-dominant sides[18]. In our present study, the CSA values were higher in males than females (p <0.05) (Tab. 2). There was no significance (p >0.05) between the mean CSA of the radial nerves with hand dominance (Tab. 3) and age of the subjects (Tab. 7). The point that there was no statistical difference between the dominant and non-dominant hands can be practically utilized for the comparison of both limbs.

Tab. 2. *Mean cross-sectional area (cm²) of both radial nerves at two levels, and their relationship with patient sex*

Sex	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
Male	105	0.02443	0.003037	$r = -0.488$ $p = 0.001$	0.02494	0.008413	$r = -0.237$ $p = 0.001$
Female	95	0.02104	0.003058		0.02142	0.005664	
Gender	**No. of cases**	**CSA level 2**					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
Male	105	0.04496	0.003611	$r = -0.486$ $p = 0.001$	0.04538	0.013641	$r = -0.225$ $p = 0.001$
Female	95	0.04095	0.003512		0.04072	0.003102	

CSA – cross-sectional area, SD – standard deviation

Tab. 3. *Cross-sectional area (cm²) of the radial nerve at two levels, and its relationship with the dominant and non-dominant sides*

Dominant side	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
Left	11	0.02342	0.002244	$r = -0.042$ $p = 0.556$	0.02389	0.002424	$r = -0.018$ $p = 0.802$
Right	189	0.02279	0.003535		0.02324	0.007624	
Dominant side	**No. of cases**	**CSA level 1**					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
Left	11	0.04400	0.002324	$r = -0.057$ $p = 0.420$	0.04376	0.002237	$r = -0.014$ $p = 0.846$
Right	189	0.04297	0.004165		0.04313	0.010640	

CSA – cross-sectional area, SD – standard deviation

Tab. 4. *Cross-sectional area (cm²) of the radial nerve at two levels, and its relationship with height*

Height	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
≤160	54	0.01935	0.002298	$r = -0.736$ $p = 0.001$	0.02017	0.006965	$r = -0.359$ $p = 0.001$
161–170	110	0.02315	0.002379		0.02310	0.002869	
>170	36	0.02705	0.002451		0.02844	0.013136	
Height	**No. of cases**	**CSA level 1**					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
≤160	54	0.03917	0.002684	$r = -0.656$ $p = 0.001$	0.03914	0.002340	$r = -0.234$ $p = 0.001$
161–170	110	0.04489	0.013782		0.04419	0.013138	
>170	36	0.04714	0.004031		0.04606	0.005176	

CSA – cross-sectional area, SD – standard deviation

High-resolution ultrasonographic evaluation of the peripheral nerves allows good depiction of nerve morphology and can identify pathological changes such as nerve enlargement and alterations in the echopattern[24–26]. Ultrasound also provides useful information about the morphology, precise location, and anatomical course of the nerve[27]. The CSA values of the radial nerve obtained in this study will establish the normal range of values, which can facilitate the diagnosis of abnormal nerve disorders such as neuropathies, trauma, tumors, and entrapment involving the nerve. All these disorders will cause a significant alteration in the CSA of the radial nerve from the normal range of values[28,29].

There are a few limitations associated with the present study. The sample population was restricted to one demographic area, and the CSA measurements were done only at two levels. Including a population from different demographic strata and taking CSA measurements at more levels could be performed to avoid these limitations.

Conclusions

The mean CSA in our present study was 2.3 ± 0.3 mm² and 4.3 ± 0.4 mm² at levels 1 and 2, respectively. Healthy subjects showed a strong correlation between the CSA of the radial nerve and height, weight, BMI, and but no correlation with age. Males had larger CSA values of the radial nerve than females. We can practically compare both dominant and non-dominant hands, as there was no statistical difference between the CSA of the radial nerves in the dominant and non-dominant hands. These normal reference values of

Tab. 5. *Cross-sectional area (cm²) of the radial nerve at two levels, and its relationship with weight*

Weight (kg)	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
≤60	49	0.01931	0.002597	*r* = 0.725 *p* = 0.001	0.02025	0.007380	*r* = 0.263 *p* = 0.045
61–70	90	0.02251	0.002163		0.02335	0.009055	
>70	61	0.02610	0.002596		0.02557	0.002272	
Weight (kg)	**No. of cases**	**CSA level 1**					
		Right		***P*-value & *r*-value**	**Left**		***P*-value & *r*-value**
		Mean	**SD**		**Mean**	**SD**	
≤60	49	0.03916	0.003223	*r* = 0.643 *p* = 0.001	0.03913	0.002741	*r* = –0.234 *p* = 0.001
61–70	90	0.04451	0.015217		0.04359	0.014653	
>70	61	0.04632	0.003528		0.04578	0.003263	
CSA – cross-sectional area, SD – standard deviation							

Tab. 6. *Cross-sectional area (cm²) of the radial nerve at two levels, and its relationship with body mass index*

BMI	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
18.5–23.0	63	0.02108	0.003902	*r* = 0.368 *p* = 0.001	0.02289	0.012558	*r* = –0.343 *p* = 0.045
23.1–25.0	61	0.02294	0.002996		0.02286	0.003150	
>25.0	76	0.02417	0.002830		0.02392	0.002755	
BMI	**No. of cases**	**CSA level 1**					
		Right		***P*-value & *r*-value**	**Left**		***P*-value & *r*-value**
		Mean	**SD**		**Mean**	**SD**	
18.5–23.0	63	0.04348	0.018645	*r* = 0.851 *p* = 0.001	0.04087	0.003869	*r* = 0.142 *p* = 0.001
23.1–25.0	61	0.04311	0.003775		0.04450	0.017814	
>25.0	76	0.04450	0.003392		0.04400	0.003420	
CSA – cross-sectional area, SD – standard deviation							

Tab. 7. *Cross-sectional area (cm²) of the radial nerve at two levels, and its relationship with age*

Age group (years)	No. of cases	CSA level 1					
		Right		*P*-value & *r*-value	Left		*P*-value & *r*-value
		Mean	SD		Mean	SD	
18–30	51	0.02214	0.003787	*r* = 0.130 *p* = 0.067	0.02257	0.012087	*r* = 0.084 *p* = 0.239
31–50	79	0.02237	0.002928		0.02271	0.003159	
≥50	70	0.02317	0.003633		0.02410	0.006411	
Age group (years)	**No. of cases**	**CSA level 1**					
		Right		***P*-value & *r*-value**	**Left**		***P*-value & *r*-value**
		Mean	**SD**		**Mean**	**SD**	
18–30	51	0.04179	0.004172	*r* = 0.059 *p* = 0.405	0.04158	0.003892	*r* = 0.066 *p* = 0.350
31–50	79	0.04409	0.004461		0.04350	0.004013	
≥50	70	0.04473	0.016338		0.04390	0.015726	
CSA – cross-sectional area, SD – standard deviation							

the radial nerve can facilitate the study of sex-specific differences, and provide information on side to side variations along with abnormal nerve conditions. Hence, these ultrasonographic reference values along with basic clinical data will aid in the diagnosis, response to treatment, and prognostic evaluation of peripheral neuropathies.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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