

MORPHOMETRIC COMPARISON OF THE HUMAN CORPUS CALLOSUM IN PROFESSIONAL MUSICIANS AND NON-MUSICIANS BY USING *IN VIVO* MAGNETIC RESONANCE IMAGING

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SUMMARY

The purpose of this study was to determine the possible morphometrical differences of the corpus callosum between professional musicians and non-musicians. Certain callosal dimensions and areas were measured in 20 professional musicians and compared with 20 age-, sex- and handedness-matched control group by using *in vivo* magnetic resonance imaging (MRI). Sagittal T1-weighted midsagittal sections were traced with the digitizer and the metric scale of the system was used for the measurements. Results were statistically analysed by independent t test. There were significant differences between the two groups both for the anterior and posterior areas of the corpus callosum. Furthermore, significant differences between the two groups were found in the thicknesses of certain parts of the corpus callosum.

Our results support the hypothesis that brain morphology is prone to plastic changes caused by environmental factors.

Key words: corpus callosum, professional musicians, morphometric comparison, magnetic resonance imaging.

RÉSUMÉ

Étude morphométrique par IRM du corps calleux chez les musiciens professionnels et chez les sujets non musiciens

L'objectif de cette étude est de déterminer les différences morphométriques du corps calleux chez les musiciens professionnels et chez les sujets non musiciens. La longueur, l'épaisseur et la surface du corps calleux ont été mesurées chez 20 musiciens professionnels et 20 personnes non musiciennes. Les coupes médianes ont été tracées et une échelle métrique a été utilisée pour les mesures. L'analyse des résultats a été faite par méthode statistique (« independent t test »). Des différences significatives ont été observées dans les deux groupes à la fois pour les parties antérieure et postérieure du corps calleux. De plus, des différences significatives ont été observées entre les deux groupes en ce qui concerne l'épaisseur de certaines parties du corps calleux. Nos résultats renforcent l'hypothèse d'une plasticité cérébrale causée par des facteurs environnementaux.

Mots-clés : corps calleux, musiciens, anatomie, Imagerie par Résonance Magnétique (IRM).

INTRODUCTION

The corpus callosum (CC) is the main fiber tract interconnecting the two hemispheres of the brain. As the largest commissural pathway, the function of this neuroanatomical structure is still unclear. It is thought to play an important role in interhemispheric integration and communication [23] Brain structures are prone to morphological changes during

growth, development and aging processes [3, 19]. In some studies growth and development were shown to continue until the third decade of life [5, 9] Environmental factors are thought to cause changes in brain morphology [3, 11, 19]. Our aim was to see whether there were any morphometric differences or not in the human CC between professional musicians and non-musicians. Routinely performing professional musicians who start training early, can be considered as exposed to environmental factors. Training, before brain development is complete, might influence changes in the growth and development of the CC. A morphometric difference in the anterior half of the CC between a group of

Received July 19, 2001. Accepted January 8, 2002.

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keyboard and string players and a group of non-musicians was already shown by Schlaug et al. [18]. In our study, we compared both the anterior and the posterior parts of the CC.

MATERIAL AND METHODS

The subjects, 20 professional musicians, all string players who described themselves as right-handers and 20 age-, sex- and handedness-matched control group of non-musicians were examined by MRI (GE Signa Superconductive 1.5 Tesla) (*table I*). Initiation of musical training for all musicians was under the age of 9. Non-musicians were selected from a group of people who never interested in music professionally. This study was approved by the local ethical committee. All subjects gave their informed consent. Sagittal T1-weighted sections of 3 mm slice thickness and 3 mm interval were used for the evaluation (TR: 400-500 msec., TE : 15-20 msec., NEX : 1-2, and matrix : 160 × 224), after correct parallel alignment of the interhemispheric plane of the brain with the sagittal plane of imaging. This is ensured by the precision of the midsagittal plane determined by the callosal sulcus separating the CC from the cingulate gyrus, the appearance of the cerebral aqueduct between the tectum and tegmentum, the V shaped roof of the fourth ventricle, the presence of the cerebellar vermis, and the complete absence of the cerebellar hemispheres. The selected slices were coded and stored on the computer and measurements were made by two independent examiners who were blind to the subject's identification data. Intraclass correlation coefficient is used for inter-observer concordance ($r = 0.91$). The outline of the CC and all the thicknesses were traced with the digitizer and the metric scale of the system was used for the measurements. For each image, the greatest antero-posterior length of the CC (AB) was measured and divided into equal parts by a perpendicular line, then AB was divided into three equal parts by two perpendicular lines, such that thicknesses MN, EF and DC were attained. Another thickness was taken by a perpendicular line crossing the point at the anterior limit of the splenium (PR). AX and PB are horizontal lines crossing the genu corporis callosi and the splenium corporis callosi, respectively. Thus we arrived at

TABLE I. — Gender, age, body height and weight distributions for the groups

TABLEAU I. — Âge, sexe, taille corporelle et poids corporel dans les deux groupes

| Groups | Valid number | Age range (years) | Mean age ± S.D. (years) | Mean body height/ S.D. (cm) | Mean body weight/ S.D. (kg) |
|---------------|----------------------------|-------------------|-------------------------|-----------------------------|-----------------------------|
| Musicians | 20 (12 women, 8 men) | 19-34 | 26.7 ± 4.4 | 170.6 ± 7.1 | 65.7 ± 9.3 |
| Non musicians | 20 (12 women, 8 men) | 19-34 | 26.6 ± 4.4 | 169.4 ± 7.4 | 65.6 ± 8.2 |

the thicknesses, DC, MN, EF, PR, AX, PB as shown in (*figure 1*). The anterior area was accepted as the part of the CC which is anterior to the MN thickness on the midsagittal section while the rest of the CC was accepted as the posterior area. All the lengths, thicknesses, anterior and posterior areas of each image were measured. The KL line representing the hemispheric antero-posterior diameter was also measured to compare as a relative index. The parameters necessitated us to use the statistical independent t test. All the results of two groups were statistically compared.

RESULTS

The mean, standard error mean, standard deviation, range, minimum and maximum values and statistical significance levels (p) of each variable for both groups are shown in *table II*. When the thicknesses were compared for two groups, significant differences were found for DC ($t_{38} = 4.133$, $p = 0.000$), EF ($t_{38} = 3.714$, $p = 0.001$), MN ($t_{38} = 3.236$, $p = 0.003$), AX ($t_{38} = 4.662$, $p = 0.000$),

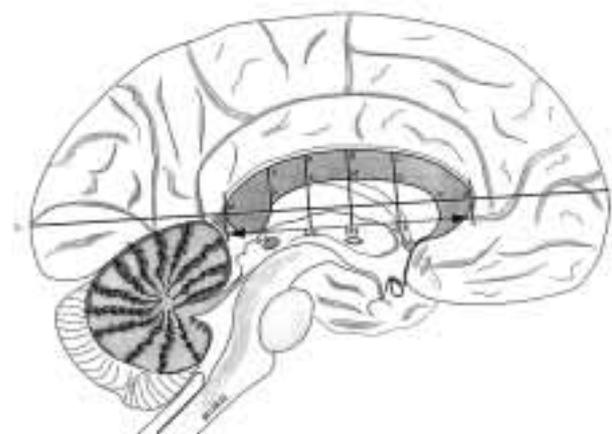


FIG. 1. — Schematic view of the CC showing the dimensions measured. AB, greatest antero-posterior length of the CC; DC and EF, thicknesses of the CC on the perpendicular lines dividing it into three equal parts; KL, extension of AB to the anterior and posterior poles of the cerebrum; MN, thickness of the CC on the perpendicular line dividing it into two equal parts; AX and PB, thicknesses of the CC on the genu and splenium corporis callosi respectively; PR, a perpendicular line crossing line AB at the anterior limit of the splenium; ANT, area of anterior half of the CC; POST, area of posterior half of the CC; TOTAL, total area of the CC.

FIG. 1. — Représentation schématique de la face médiale du cerveau. AB : plus grande longueur du corps calleux. DC et EF : épaisseur du corps calleux à l'union des tiers antérieur et moyen et des tiers moyen et postérieur du corps calleux. KL : longueur de l'hémisphère cérébral passant par AB. MN : épaisseur du corps calleux au milieu de AB. AX et PB : épaisseur du genou et du splénium du corps calleux. PR : perpendiculaire à AB à hauteur de la limite antérieure du splénium. ANT : surface de la moitié antérieure du corps calleux. POST : surface de la moitié postérieure du corps calleux. TOTAL : surface totale du corps calleux.

TABLE II. — Descriptive Statistics
 TABLEAU II. — Valeur des différents paramètres étudiés

| | Groups | Min | Max | Mean \pm SEM | SD | P |
|---------------|--------|--------|--------|--------------------|--------|-------|
| AB | M | 62.00 | 76.00 | 69.85 \pm 0.91 | 4.07 | 0.910 |
| | NM | 61.00 | 77.00 | 70.00 \pm 0.95 | 4.27 | |
| DC* | M | 5.00 | 9.00 | 6.75 \pm 0.26 | 1.16 | 0.000 |
| | NM | 4.00 | 7.00 | 5.40 \pm 0.20 | 0.88 | |
| EF* | M | 4.00 | 9.00 | 5.80 \pm 0.30 | 1.32 | 0.001 |
| | NM | 3.00 | 7.00 | 4.40 \pm 0.23 | 1.05 | |
| PR | M | 6.00 | 16.00 | 10.65 \pm 0.63 | 2.81 | 0.060 |
| | NM | 6.00 | 13.00 | 9.15 \pm 0.45 | 2.01 | |
| KL | M | 134 | 169.00 | 150.60 \pm 1.94 | 8.67 | 0.168 |
| | NM | 137 | 158.00 | 147.20 \pm 1.45 | 6.47 | |
| MN* | M | 5.00 | 8.00 | 6.05 \pm 0.22 | 1.00 | 0.003 |
| | NM | 3.00 | 7.00 | 4.95 \pm 0.26 | 1.15 | |
| AX* | M | 9.00 | 15.00 | 12.25 \pm 0.36 | 1.62 | 0.000 |
| | NM | 6.00 | 12.00 | 9.80 \pm 0.38 | 1.70 | |
| PB* | M | 9.00 | 15.00 | 11.85 \pm 0.35 | 1.57 | 0.002 |
| | NM | 6.00 | 14.00 | 10.00 \pm 0.44 | 1.97 | |
| ANT.* | M | 242.00 | 517.00 | 369.75 \pm 15.15 | 67.76 | 0.000 |
| | NM | 185.00 | 400.00 | 285.45 \pm 12.28 | 54.91 | |
| POST.* | M | 255.00 | 463.00 | 337.65 \pm 12.80 | 57.24 | 0.000 |
| | NM | 110.00 | 352.00 | 239.65 \pm 14.03 | 62.74 | |
| TOTAL* | M | 540.00 | 980.00 | 707.40 \pm 24.30 | 108.66 | 0.000 |
| | NM | 401.00 | 752.00 | 525.10 \pm 18.78 | 84.00 | |

SEM : Standard Error of Mean, **SD** : Standard Deviation. The values for lengths and thicknesses are in mm and for areas in mm². * : Statistical significance of the lengths, thicknesses DC, EF, MN, AX, PB and areas of the CC is mentioned ($p < 0.05$). n = 20 for both groups.

PB ($t_{38} = 3.285$, $p = 0.002$). When the lengths were compared for two groups, no significant differences were found. When the areas were compared for two groups, significant differences were again found for both the anterior ($t_{38} = 4.323$, $p = 0.000$) and posterior ($t_{38} = 5.160$, $p = 0.000$) halves of the CC (figures 2, 3, 4 and 5).

DISCUSSION

There is a large variation in callosal size in different groups, the significance of which is still open to debate. In addition to handedness-related differences seen in the human CC, a larger midsagittal CC size is also thought to be seen in more symmetrically organized brains, in increased ambilaterality as found in left-handers and in subjects with right hemisphere language dominance [6, 8, 10, 12, 13, 20,

24, 25]. Another dispute for callosal size and shape is between men and women groups [2, 4, 5, 8, 12, 14, 21]. All these differences are said to be explained by the same theories such as regressive events (like death of neurons), elimination of axon collaterals and environmental factors [19].

According to Pujol *et al.* [16] maturation of the CC was shown to extend into late adolescence and be the latest fiber tract in the central nervous system to be myelinated. Animal studies show that remodeling of axon collaterals occur in the postnatal development of the CC because in adults the number of callosal axons is much less than in neonates. Juraska and Kopcik examined sex and environmental influences on the size and ultrastructure of the rat CC and stated that sex differences existed in axonal number and size, and that the environment influenced these differences [11]. During early development, reduction of the callosal axons

can be manipulated by continuous sensory and motor stimulation such as seen in musicians (listening to the music and playing instruments) who start training in early ages. Certain permanent functional transformations might arise in particular sys-

tems of neurons as a result of appropriate stimuli or their combination during development. The corresponding changes are defined as plastic changes which are supported by animal and human studies [16].

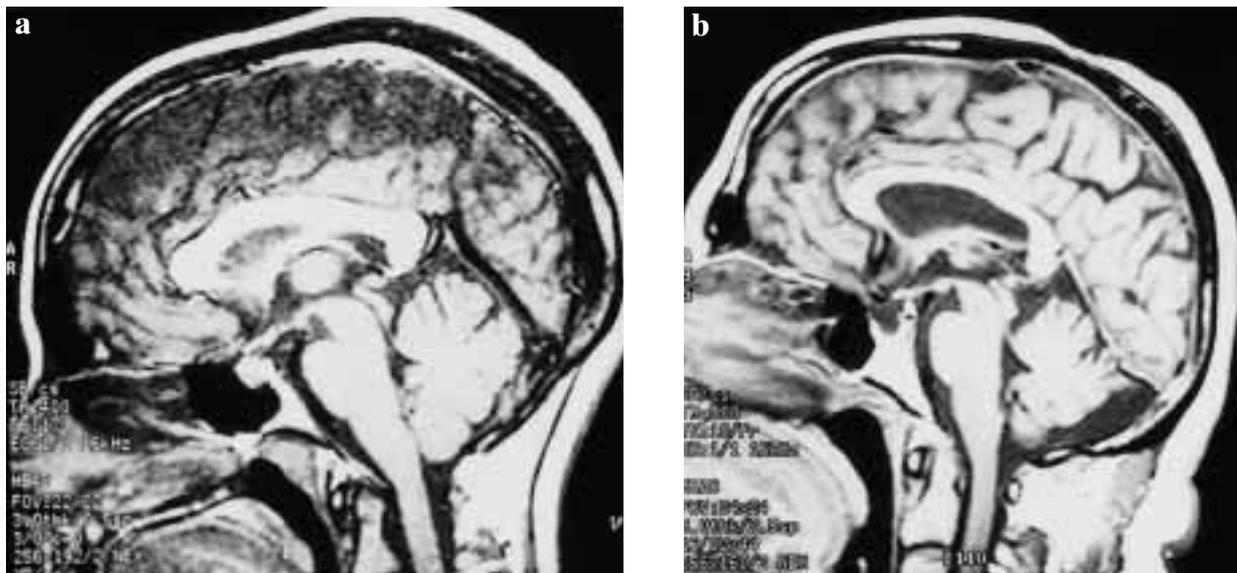


FIG. 2. — MRI images of a female professional musician (a) and a female non-musician (b).

FIG. 2. — *Imagerie par Résonance Magnétique (IRM) : coupes sagittales et médianes chez une femme musicienne professionnelle (a) et une femme non musicienne (b).*

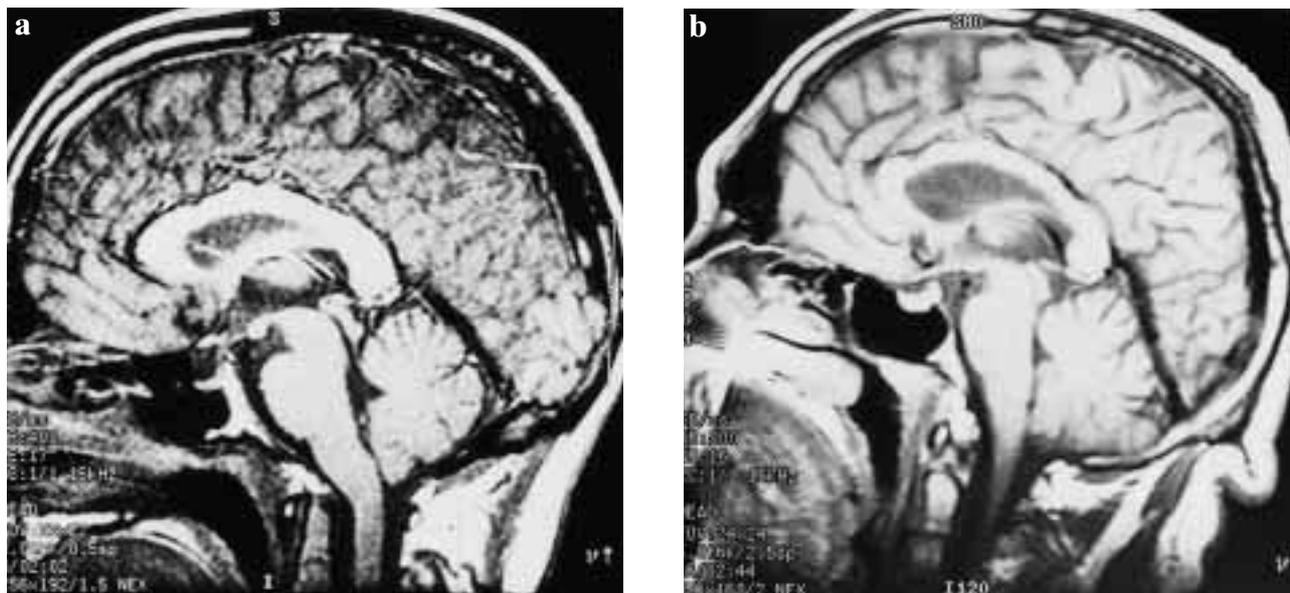


FIG. 3. — MRI images of a male professional musician (a) and a male non-musician (b).

FIG. 3. — *IRM : coupe sagittale médiane chez un homme musicien professionnel (a) et un homme non musicien (b).*

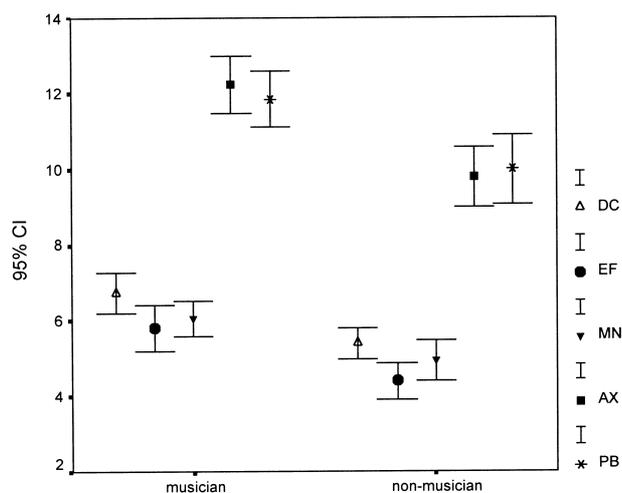


FIG. 4. — Schematic comparison of the statistically significant thicknesses of the CC between musicians and non-musicians; CI, confidence interval.

FIG. 4. — Représentation schématique des valeurs de l'épaisseur du corps calleux variant de façon statistiquement significative dans les deux groupes. CI : intervalle de confiance.

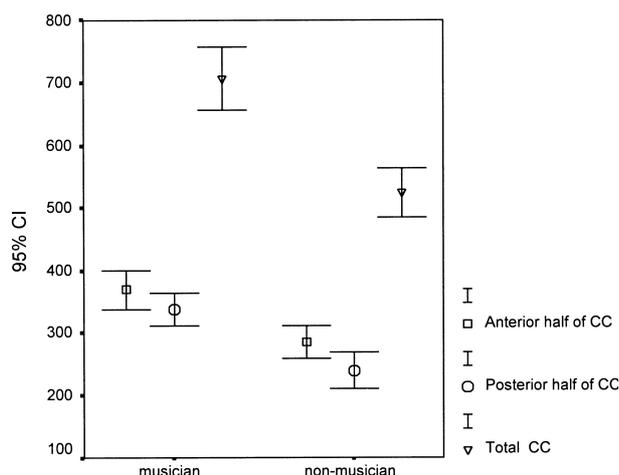


FIG. 5. — Schematic comparison of the areas of the anterior and the posterior halves and the total area of the CC between musicians and non-musicians; CI, confidence interval.

FIG. 5. — Représentation schématique des surfaces de la moitié antérieure et de la moitié postérieure et de la surface totale du corps calleux dans les deux groupes. CI : intervalle de confiance.

Aboitiz et al. examined the fiber composition of the human corpus callosum [1]. In the human, the region with the highest density of large callosal fibers is the posterior midbody, and it is proposed to represent the primary and the secondary auditory areas. As one of the final conclusions they clarify that the callosal area may be considered a good estimator of total fibers in the human CC [1]. De Lacoste et al. have demonstrated that callosal connections from the temporo-parieto-occipital

junctional region coursed through the splenium and the caudal portion of the human CC [7]. Anatomical studies by Pandya and Seltzer concerning the size difference in the anterior half of the CC, shows that in the rhesus monkey fibers mainly connecting frontal motor-related and prefrontal cortices cross through this part of the CC [15].

The study of Schlaug et al. reveals a size difference in the midsagittal area of the anterior half of the CC between controls and professional classical musicians (keyboard or string players, or both) with an early commencement of musical training. They explain the size difference in the anterior half of the CC within the concept of cerebral plasticity as an adaptive structural-functional process. According to them, intense bimanual motor training of musicians could play an important role in the determination of callosal fiber composition and size [18]. In the present study, our results are consistent with those of Schlaug's for the anterior half of the CC. They have found no significant results in the posterior part of the CC between musicians and controls. Containing the auditory association cortex, the planum temporale is located in the posterior superior temporal gyrus which processes sound signals. And this region was previously shown to be a marker of structural and functional asymmetry. According to Schlaug et al. it was more lateralized to the left in musicians who had perfect pitch than non-musicians and musicians without perfect pitch [19]. The results of our study suggest that, during the development of the CC, intense stimulation of the auditory cortices of professional musicians could also play an important role in the determination of callosal fiber composition and size in the posterior part of the CC. Theoretically, it is thus logical to interpret that chronic stimulation of the auditory cortices can be effective and cause plastic changes as an adaptive structural-functional process also in the posterior half.

Recent functional imaging studies already suggested that certain abilities unique to musicians relied on specialized cortical representations in both hemispheres and a more distributed network than those of non-musicians. Furthermore, certain cortical areas such as the premotor cortex and the supplementary motor area play a particular role in the temporal control of sequential motor tasks and the integration of bilateral motor behavior [18]. In a study by Steinmetz et al., they pointed out an inverse relationship between brain size and callosal connectivity. Due to increasing fiber length, conduction delay via the CC must be expected to increase with forebrain size. So transcallosal connections of homotopical cortical points may become functionally less advantageous and diminish with an enlarging brain. It has been suggested on theoretical grounds that this may be the principle underlying the development of hemispheric specialization and asymmetry

[22]. Sacks suggests that talents such as musical ability can also be explained by the development of specialized focal neural networks or enlargement of primary or secondary cortices of related regions such as seen in autistics, savant syndrome and Williams syndrome [17]. Callosal size alone can not determine the quality of interhemispheric transfer, since the number of its axons and the pattern of their synaptic connections are also critical. Indeed, functionally important differences in callosal composition might occur even in the absence of morphologically detectable changes in callosal size [3].

The general concept is that, because of time constraints of interhemispheric transfer, abilities such as playing musical instruments should be controlled by one hemisphere only. Moreover different components of such a talent is controlled by one or the other hemisphere. So one might ask why we need a larger callosa if there is hemispheric specialization. In some other recent studies it has been suggested that larger callosal area might indicate a higher capacity for interhemispheric transfer [21, 25]. If so what is the aim of larger interhemispheric transfer? Is it a control mechanism and an information complementary system over each part of the hemispheres? There are still many questions yet to be answered. In spite of all these studies, our present information does not provide conclusive results because certainty of the morphometric studies are still conflicting. These morphometric studies have to be complemented by postmortem anatomical investigation of the relationship between micro- and macrostructure both in human and animal studies. It seems that it is still a question whether there is a specialized cortical network or whether it is gained by intensive training in musicians, or both. Our study and others should also be complemented by new studies made by newly available techniques such as positron emission tomography (PET) and functional MRI which are the techniques used to identify regions of the brain involved in performing specific tasks.

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