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C. R. Biologies 329 (2006) 319–329
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BIOLOGIES
http://france.elsevier.com/direct/CRASS3/

Neurosciences

Vincenzo Malacarne (1744–1816): a researcher in neurophysiology between anatomophysiology and electrical physiology of the human brain

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Received 15 November 2005; accepted after revision 15 February 2005

Available online 5 May 2006

Abstract

Since his first years at Turin until the last years of his life at Padua, Vincenzo Malacarne devoted most of his time to the examination of the structures and the various parts of which the cerebellum and the human brain are composed. He is rightly considered as one of the first to have correctly described the anatomy of the cerebellum, as well in the field of human anatomy and comparative anatomy. However, his work cannot be reduced to these studies. He worked out a cerebral physiology, with organic and intellectual phenomena in mind, established on an anatomopsychic parallelism. This parallelism is itself founded on a rational and mathematical criterion: the number of lamellae contained in the cerebellum. A letter written by him in 1792 and addressed to Abbot Denina was recently found by the present author in November 2005 at the Academy of Sciences of Turin. Malacarne exposed his project of studying the animal electricity put forward by Galvani within the cerebral organ. May it be that Malacarne had in mind the physiology of his time while trying to record an electric activity within the brain? ***To cite this article: C. Cherici, C. R. Biologies 329 (2006).***

Résumé

Vincenzo Malacarne (1744–1816) : un chercheur en neurophysiologie entre anatomophysiologie et physiologie électrique du cerveau humain. Depuis ses premières années à Turin aux dernières années de sa vie à Padoue, Vincenzo Malacarne se consacra à l'examen des structures des différentes parties dont sont composés le cervelet et le cerveau humain. Il est considéré, à raison, comme l'un des premiers à avoir correctement décrit l'anatomie du cervelet, tant dans le champ de l'anatomie humaine que dans celui de l'anatomie comparée. Pourtant, on ne peut réduire ses travaux à ces études, car il élabore une physiologie cérébrale tenant compte parallèlement des phénomènes organiques et intellectuels, fondée sur un parallélisme anatomopsychique. Ce dernier est lui-même fondé sur un critère rationnel et mathématique : le nombre de lamelles contenues dans le cervelet. Une lettre de 1792 adressée à l'abbé Denina, écrite par Malacarne, a été retrouvée par l'auteur en novembre 2005 à l'Académie des sciences de Turin. Il y expose un projet relatif à la recherche, au sein de l'organe cérébral, de l'électricité animale mise en exergue par Galvani. Se peut-il qu'il se soit penché sur la physiologie de son époque en essayant d'enregistrer une activité électrique au sein du cerveau ? ***Pour citer cet article : C. Cherici, C. R. Biologies 329 (2006).***

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1631-0691/$ – see front matter
doi:10.1016/j.crvi.2006.03.003

Keywords: Cerebellum; Lamella; Intellect; Physiology; Volta's battery; Animal electricity

Mots-clés : Cervelet ; Lamelle ; Intellect ; Physiologie ; Pile de Volta ; Électricité animale

1. Introduction

Vincenzo Malacarne (1744–1816) is an important scientist in the history of medicine and neuroanatomy. He contributed to the surgical and therapeutical evolution of mental illness like hydrocephalus or cretinism. He took part to the developments of the sciences devoted to the human brain. For instance, he was one of the first to examine the cerebellar lamellar structures and to observe the variability of lamellae's number in the internal stratum. He observed that this number changed throughout animal species, from chicken to human. His first researches on the cerebellum were published in 1776. Between 1776 and 1780, he described a universal anatomy of human brain that can be regarded as a model for anatomy. Moreover, as he founded his physiology on anatomical criteria, his universal neuro-anatomy was dedicated to surgeons and physiologists. He is considered as the founder of topographical anatomy and he was probably one of the first to apply a topology to the study of brain parts.

Nevertheless, he was never considered as a physiologist. In fact, during a visit in Malacarne's funds at the Academy of Sciences of Turin, some documents were recently found by me, among which a large quantity of handwritten papers and letters attesting a project devoted to physiological experiments on brain and cerebellum. One main question can be asked: did Malacarne perform physiological experiments?

Malacarne is not known as an actor in the history of animal electricity. However, thanks to the documents found, it has become indubitable that he carried out studies related to Galvani's discovery and the pattern of Volta's battery. Did he publish an article on this project? In what ways was he able to experiment on human brain in order to record animal electricity? Was it only a theoretical project?

2. Anatomophysiological approach to the function of human cerebellum

The stages of Malacarne's anatomical work can be established from two important texts on the anatomy of dissimilar parts of human cerebral organ: *Nuova esposizione della vera struttura del cervelletto umano* [1], published in 1776 and *Encefalotomia nuova universale* [2] in 1780. Between 1776 and 1808, an evolution in his thought can be perceived. Since his texts are related to each other systematically, we may achieve a coherent reading of them, where general problems, like intellectual faculties, functions of human brain and cerebellum and anatomophysiological approaches are displayed. In other words, Malacarne progressively worked from the field of anatomy to an anatomophysiological approach of the human cerebral organ.

If we consider where such problematic occurs in these texts and their insertion in the clinical, anatomical and surgical fields, we find that studies devoted to the brain, cerebellum and nervous system kept Malacarne busy from the beginning of his observations at Turin up to the end of his career at the important University of Padua. In order to see the degrees in the evolution of his thought and theories, between fundamental research and peculiar cases, we wish to correlate his texts with numerous 'opuscules' regarding human and animal teratology, surgery, comparative anatomy and physiological systems. This approach allows the contemporary reader to consider Malacarne not only as a neuroanatomist, but also as a physiologist.

Nevertheless, we must not forget that his physiology rests on two concepts: pattern and function. Thus, his physiological work is supervised by these concepts and by the anatomopathological and clinical method. We may say that he conceived a sort of human cerebral functioning. A general problematic ties together his texts. It allows a reading where an evolution can be found, from an anatomical neurology to anatomical physiology and human clinics of brain and cerebellum.

Since 1776, Malacarne elaborated a topographical anatomy of different parts of the human brain with demarcations of organic areas. It is significant to highlight that for all of them, he reconstituted their anatomical links with surrounding parts. For instance, he described natural links to which higher parts of the cerebellar organ are mutually linked: the right one with the left one, the anterior one with the posterior one, and the latter two with cerebral nerve roots. His anatomophysiological theories were partly established on topographical observations made on the human cerebellum. Numerous handwritten commentaries found in a copy of the *Encefalotomia nuova universale* indicate that cerebral activity was thought as directed by a harmonious functioning within a hierarchy of cerebral parts. This idea was established on patterns and connexions of anatomical structures. In other words, this harmonious functioning depended intimately on the integrity of structures and their mutual harmony.

Indeed, the way he elaborated an anatomopathological and clinical method applied to the human cerebral organ is deduced from correlations of anatomical and pathological studies made in his *Encefalotomia nuova universale* [3] and the handbook on human cerebellum [4], and above all in his *Osservazioni in chirurgia* [5]. All his anatomophysiology was established on this method, which is based on the correlation between clinical and anatomopathological observations made on mental patient. He founded a cerebral physiology and studied mental and organic phenomena in parallel from various brain structures.

In 1794, he presented in his *Prime linee di chirurgia* [6] an anatomophysiology of animal faculties. They encompassed all faculties of human intellect: reason, imagination, memory, and discernment. Their appropriate extent and expression could not be disconnected from the perfection of human intellect on which they depend. This theory was supported by observations made on pathological cerebral cases where internal lesions seemed to be at the origin of mental alterations. At the same time, distortions of human behaviours are equally correlated at the same organic origin. In particular, Malacarne studied few cases of hydrocephalus and cretinism. He established the anatomopsychological parallelism which marked his physiological theory of human cerebellum, with correlation between organic perfection and intellectual faculties. Thus, correlating his anatomical, pathological and clinical observations, he established a functional theory of the cerebellum. It included links between mental and behavioural alterations and lesions seen during autopsies made on persons with cretinism or hydrocephalus. Malacarne correlated cerebellum compression with alterations of intellect. According to him, normal intellect can only be expressed in healthy organs. All these studies cannot be separated from his research on a universal anatomy of the human brain that provided a pattern to confront all anatomical variations.

A topographical anatomy of cerebral parts injured by illness is also achieved. Malacarne thus contributed to underpin the anatomopathological and clinical aspects of cretinism and hydrocephalus. Regrouping similar clinical and post-mortem observations, a general outline of organic and moral alterations was made. He noticed cerebellum compression in cretinism associated with anatomical alterations and a growth deficiency of the constituent elements of the cerebellar internal stratum. He elaborated a hypoplasic theory of cerebellar malformations regarded as the origin of intellectual deficits. He envisaged the human cerebellum as the organic seat of all intellectual faculties. This theory was equally reinforced by its opposite side, namely the hyperplasy observed on gifted persons.

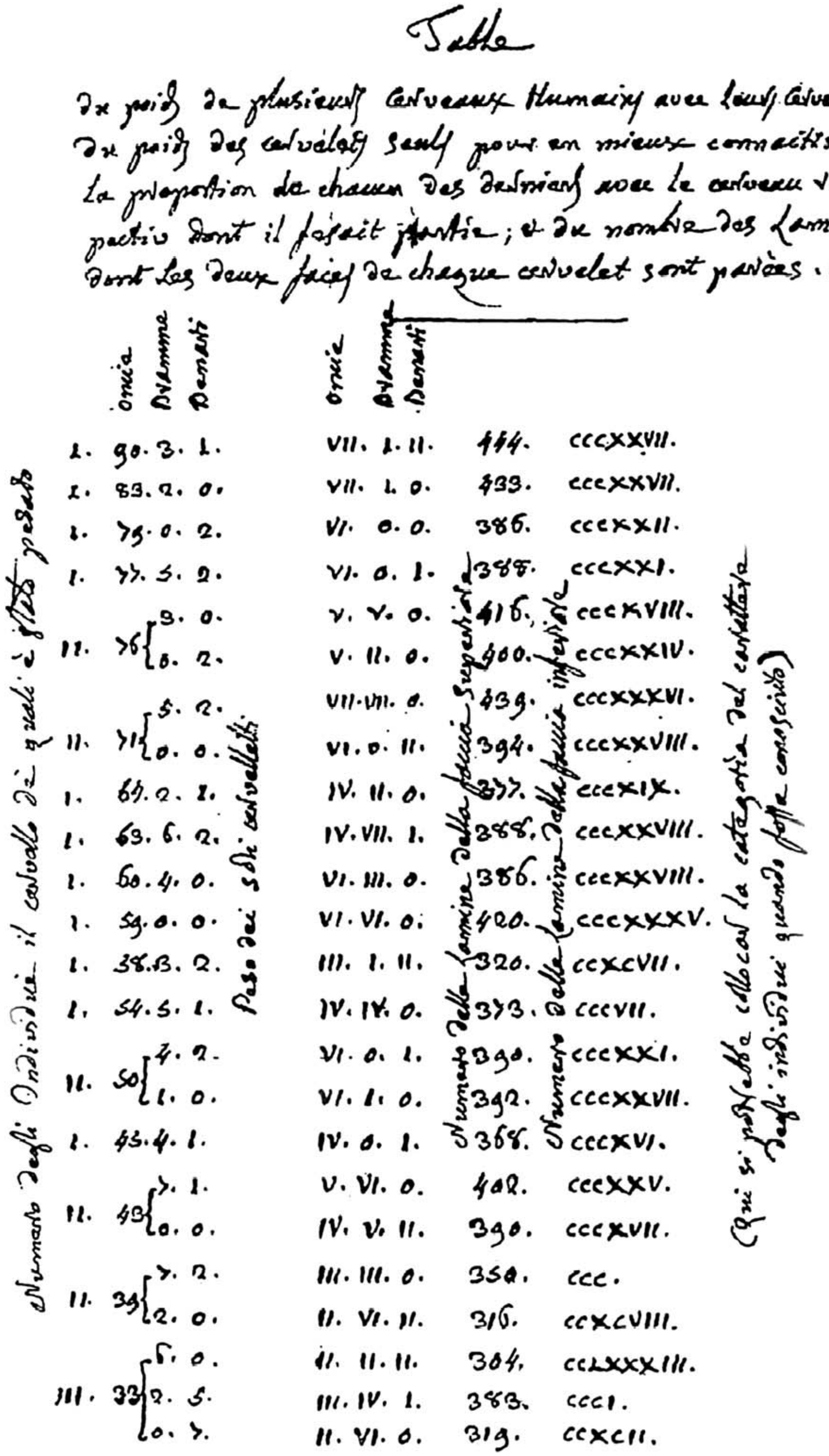
Although the medical field of madness and mental deficits was not well differentiated from general researches on human brain functioning, Malacarne apprehended in parallel brain lesions and intellect. The way in which external sensations merge with internal common sense was also analysed in correlation with the effects of lesions associated with this sense.

Malacarne quantified the units of the cerebellar internal structures, the lamellae being numbered for a systematic description of the human cerebellum. For him, the mental faculties depended on their number. He rationalized the distinction between healthy and injured cerebral parts according to anatomophysiological and clinical observations. He considered a relation between the number of cerebellar lamellae and the expression of intellectual faculties. In this way, may we say that he made statistics on human faculties?

In one of his tables based on a study from sixty subjects [7], he included results taken from organs from healthy and mentally ill persons. These variations included between 340 and 810 lamellae, the average being about 600 lamellae (Fig. 1).

The dissection method is found in a handwritten annotation that we found in one of his copy of the *Encefalotomia nuova universale*. It illustrates the way he calculated these numbers:

> "*From these sections, I know exactly the number of lamellae that compose different cerebella in less than ten minutes. Here is in what way: I cut in oblique line the right hemisphere from the right edge towards the centre to the main convexity of the posterior expanse of this hemisphere. I count the white strips which are clearly visible on the right cut surface made. I count the exactly number of lamellae composing all layers, lobe by lobe within this hemisphere. For instance, I reckon one hundred and twenty lamellae and I want to be surer about it. I reckon these extremely visible lamellae in the left surface in the vertical cut. I make another vertical longitudinal cut of the lamellate tongue that lies in the ventricle of the cerebellum superior edge, from the radices to the hemisphere perpendicular commune curvature. And I cut crosswise in the valley of cerebellum. First of all, I reckon white strips in the cut right edge. I found for example one hundred and eighty-four. Then, I check this number on the opposite edge of this same cut. I cut in the*



Table

du poids de plusieurs Cerveaux Humains avec leurs Cervelets, du poids des cervelets seuls pour en mieux connaître la proportion de chacun des derniers avec le cerveau respectif dont il faisait partie; et du nombre des Lamelles dont les deux faces de chaque cervelet sont parées.

Numero degli Individui il cervello de' quali è stato pesato

Peso dei soli cervelletti

Numero delle lamine della faccia superiore

Numero delle lamine della faccia inferiore

Qui si potrebbe collocar la categoria del carattere degli individui quando fosse conosciuto

	oncia	dramme	denari	oncie	dramme	denari		
I.	90.	3.	1.	VII.	I.	II.	444.	CCCXXVII.
I.	83.	2.	0.	VII.	I.	0.	433.	CCCXXVII.
I.	75.	0.	2.	VI.	0.	0.	386.	CCCXXII.
I.	77.	5.	2.	VI.	0.	I.	388.	CCCXXI.
II.	76	3.	0.	V.	V.	0.	416.	CCCXVIII.
		6.	2.	V.	II.	0.	400.	CCCXXIV.
II.	71	5.	2.	VII-VIII.		0.	439.	CCCXXXVI.
		0.	0.	VI.	0.	II.	394.	CCCXXVIII.
I.	64.	2.	1.	IV.	II.	0.	377.	CCCXIX.
I.	63.	6.	2.	IV.	VII.	I.	388.	CCCXXVIII.
I.	60.	4.	0.	VI.	III.	0.	386.	CCCXXVIII.
I.	59.	0.	0.	VI.	VI.	0.	420.	CCCXXXV.
I.	58.	3.	2.	III.	I.	II.	320.	CCXCVII.
I.	54.	5.	1.	IV.	IV.	0.	373.	CCCVII.
II.	50	4.	2.	VI.	0.	I.	390.	CCCXXI.
		1.	0.	VI.	I.	0.	392.	CCCXXVII.
I.	45.	4.	1.	IV.	0.	I.	368.	CCCXVI.
II.	40	7.	1.	V.	VI.	0.	402.	CCCXXV.
		0.	0.	IV.	V.	II.	390.	CCCXVII.
II.	39	7.	2.	III.	III.	0.	350.	CCC.
		2.	0.	II.	VI.	II.	316.	CCXCVIII.
III.	33	5.	0.	II.	II.	II.	304.	CCLXXXIII.
		2.	5.	III.	IV.	I.	383.	CCCI.
		0.	7.	II.	VI.	0.	319.	CCXCII.

Fig. 1. Casuistry table of Malacarne. Numbers given in this table come from Malacarne's studies made on sixty human cerebella and brains. The table is from the Bonnet's funds in the Public and University Library of Geneva. Column A indicates the number of subjects whose brain has a similar weight. Column B indicates ounces (between 24 and 33 g) of each human brain weight. In column C are eights (one eight is 4 g). In column D are scruples (between 1 and 1, 5 grams) brain weight. In column E, data relate to isolated cerebella. Column E indicates ounces from cerebella. Column F are eights and column D the scruples. Column H indicates the number of lamellae found on the superior side of each cerebellum and column I the number of lamellae numbered on the inferior side.

same way (oblique and vertical), the left hemisphere as the right. Diverging at the level of the radices, from the examination of the two sides, with one hundred and twelve strips, I have already four hundred and sixteen lamellae. Doing the same operations on the tonsils, from which I have forty-two lamellae, I study nuclei. It is obvious that the cerebellum I have examined has four hundred and eighty-four lamellae. I did not even spend ten minutes to check and count this number." [8]

We must underline the great coherence between Malacarne's fundamental research on a universal brain anatomy and his clinical and pathological opuscules published between 1776 and 1784. We must also highlight the move of his thought during this period. Clearly, he established and formalised a theory on cerebellar anatomophysiology that explained organic and intellectual lesions in parallel. His observations can be considered as a real experimental approach. In other words, he centred his research on anatomophysiology from his first researches on a universal neuroanatomy to his studies of intellectual deficits. Thus, his observations were made in a physiological and clinical framework.

The context of Volta's work of and Galvani's discovery of animal electricity changed the ways in which the functions of the human body were considered. Was Malacarne interested in these researches? Did he work on the animal electricity? Did he make physiological experiments in order to record this electricity in the human body?

3. From the anatomophysiology to a physiological project

Marco Piccolino's researches highlight the historical and scientific importance of the demonstration given in 1791 by Luigi Galvani about "*the presence in living tissues of an intrinsic form of electricity involved in nerve conduction and muscle contraction*." [9]

He also underlines this discovery that led to the invention by Alessandro Volta of the electric battery. In this context, dominated by investigations on electrical effects, Malacarne was found to have led down the foundations of a project on the recording of brain electricity. The letter from Malacarne we recently found was addressed in 1792 to his friend Abbot Denina, member of the Royal Academy of Berlin. It highlights the evolution of Malacarne's studies from brain anatomy to a physiological project established on an experimental approach of animal electricity. Indeed, he wrote to Denina about Galvani's research context and the possibilities to record electricity in the human brain (Fig. 2):

"*I immediately answer you by sending a compilation of all printed material in Pavia and Turin on animal electricity after the beautiful and bright experiments of Galvani of Bologna. So you shall find Valli's letters, Brugnatelli's collection and three volumes from the library of Turin on this same electricity*." [10]

Malacarne regretted the absence of any physiological experimentation on the human brain devoted to find an origin of animal electricity. He led down the foundations of such an experimental approach:

"*Mister Senebien, in his letter from Geneva written on 22 August, regrets that no direct experiment had been done on brain electricity*." [11]

In other words, we can consider Malacarne supposed 1792 animal electricity can originate in the cerebral substance. One has to recall that in 1779, Malacarne mentioned the existence of a nervous brain fluid in a letter addressed to Charles Bonnet. Malacarne compared the strength of the soul with a secret strength acting on all human nerves. He substituted the notion of animal spirits with this nervous fluid of mysterious strength. The soul was compared to an electric fire in order to show that an immaterial concept could have material effects. In other words, he made an analogy between electric fire and the human soul. Indeed, in the context of discussions on the seat of soul and its action onto the human body, Malacarne wrote in 1779:

"*Can electric fire be agitated during an indivisible moment, thanks to a secret strength, thanks to its high and astounding rapidity, by thousands corpuscles and extremely different organs, and communicate to each other, an impression equally lively at the closest and the most remote parts from the electric machine? And however, electric fire is material. This simple substance called soul (if it is considered as a vulgar comparison between material and immaterial things) thanks to an equally secret strength, absolutely mysterious can act at the same time onto different nerves and receive impressions made in this act onto diverse nerves without being constrained to be extended up to the origins of all nerves that are not so close as we previously thought. Thanks to this mysterious strength, can the soul be present in its own way without being indispensable to a sensory*

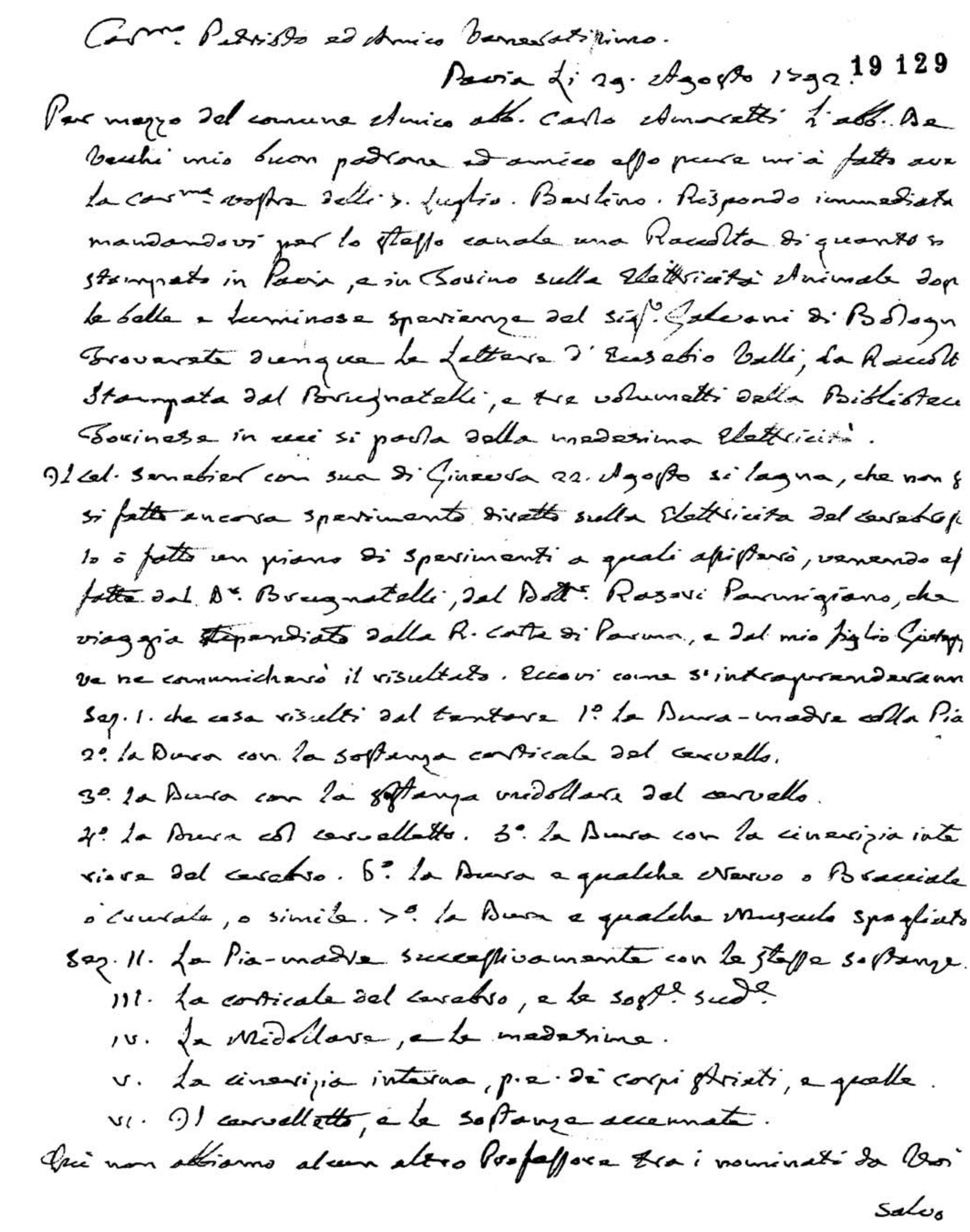

Car.mo Patriotto ed Amico Veneratissimo.
Pavia li 29. Agosto 1792. 19 129
Per mezzo del comune Amico abb. Carlo Amoretti l'abb. De
Vecchi mio buon padrone ed amico asso piace mi à fatto aver
la car.ma vostra delli 2. luglio. Berlino. Rispondo immediata
mandandovi per lo stesso canale una Raccolta di quanto si
stampato in Pavia, e in Torino sulla Elettricità Animale dopo
le belle e luminose sperienze del sig.r Galvani di Bologna
Troverete dunque la Lettera d'Eusebio Valli; la Raccolta
Stampata dal Brugnatelli, e tre volumetti della Biblioteca
Torinese in cui si parla della medesima Elettricità.
Il cel. Senebier con sua di Ginevra 22. Agosto si lagna, che non si
si fatto ancora sperimento diretto sulla Elettricità del cervello
Io ò fatto un piano di sperimenti a quali assisterò, venendo es
fatte dal D.r Brugnatelli, dal Dott. Rasori Parmigiano, che
viaggia stipendiato dalla R. Corte di Parma, e dal mio figlio Giuseppe
ve ne comunicherò il risultato. Eccovi come s'intraprenderanno
Sag. I. che cosa risulti dal tentare 1° la Dura-madre colla Pia
2° la Dura con la sostanza corticale del cervello.
3° la Dura con la sostanza midollare del cervello.
4° la Dura col cervelletto. 5° la Dura con la cinerizia inte
riore del cervello. 6° la Dura e qualche Nervo o Brachiale
o Crurale, o simile. 7° la Dura e qualche Muscolo spogliato
Sag. II. La Pia-madre successivamente con le stesse sostanze.
III. La corticale del cervello, e le sost.e sud.e
IV. La Midollare, e le medesime.
V. La cinerizia interna, p.e. dei corpi striati, e quella.
VI. Il cervelletto, e le sostanze accennate.
Qui non abbiamo alcun altro Professore tra i nominati da Voi
Salvo

Fig. 2. Letter from Vincenzo Malacarne addressed to Charles Denina, a member of the Academy of Berlin. Malacarne wrote on his project to experiment on pieces of brain and cerebellum in order to find the origin of animal electricity.

activity determined in some places of the cerebral organ?" [12]

It is not surprising that Malacarne himself was interested in Volta and Galvani's experiments. Although, he conceived an experimental approach of the recording of nervous systems activities, we may ask how he formalized and envisaged to accomplish this project.

In his letter addressed to Carlo Denina [13], Malacarne detailed the different parts to be successively punched out from a whole brain in order to make discs of tissue to be inserted in the galvanic pillar:

"Here is how we shall proceed:

Cut 1: Here is what we shall do: (1) dura mater with pia mater, (2) dura mater with cortical sub-

stance of brain, (3) dura mater with medullary substance of brain, (4) dura mater with cerebellum, (5) dura mater with ash substance of brain, (6) dura mater with some nerves as brachial, crural one or similar, (7) dura mater and some muscles undressed.

Cut 2: Pia mater successively with the same substances.

Cut 3: Cortical substance of the brain and successively the similar substances.

Cut 4: Medullar substances and the similar other.

Cut 5: Internal ash substance, corps striated and the other substances.

Cut 6: Cerebellum and the substances approached." [14]

Malacarne explained in which order parts of the human brain must be cut and studied to show the existence of animal electricity. However, he did not yet talk about possibilities to record from these parts.

We must also notice that he did not give the results of this project which was instead established on brain dissections. We can think Malacarne did not yet perform these experiments in 1792. With this text Malacarne approached another level of study. Indeed, he went from an anatomical approach to cerebral physiology. Malacarne is traditionally regarded as an anatomist. We showed he was equally a physiologist. Now from this letter, we are allowed to assert he was also impregnated with preoccupations and innovations of the new science of his time.

In his explanation given in 1779 on the action of the soul, Malacarne used already the metaphor of electric fire and that of the functioning of an electric machine. This metaphor must be replaced within the context of his work on animal economy. Between 1797 and 1803, Malacarne thought the human organism in terms of secret strength, nervous fluid, circulation of fluids and substances, and nervous transmission. He equally developed a theory of human physiology within hierarchical systems under the control of the harmony and balance of the organism. Among these systems, the nervous system was considered one of the most important, because it allowed the double expression of intellectual faculties and corporeal actions.

Did Malacarne perform the project described in his letter? What was the influence of Volta's battery made in 1800 onto his research on animal electric flow? Did he compare the structure of batteries with cerebral circumvolutions?

4. Recordings of animal electricity in parts of human and animal brain and the analogy between Volta's battery and lamellar structures

Volta's experiments and researches were made between 1792 and 1808. In this context, Malacarne began a plan of research with the purpose to find a passage for animal electricity through cerebral parts. The question was whether there was in the human brain an organic point of origin for the nervous strength?

Malacarne wished to demonstrate the possibility to record electricity in the human brain. Therefore, he wished to prove that Galvani's electricity was localised in circumvolutions. This is why he described a metaphor of brain circumvolutions with the pattern of Volta's electric battery. His aim was to experiment on the thinking organ and to find out in what ways could animal electricity be recorded. In this sense, Malacarne did lay down the theoretical foundations of the recording of brain activity. In 1808, Malacarne wrote (Fig. 3):

"*Knowing the cerebellum's organisation in particular, and maybe from the more watchful examination of the brain and the spinal marrow which constitutes this internal organ regarded as something similar to Volta's galvanic pillar, we may search by experimentation whether it can be the principal origin of the animate and material Galvanic fluid of the human machine.*" [15]

The same year, Malacarne had exposed these questions to the *Accademia Reale delle Scienze, Lettere ed Arti* of Padua on 24 March 1808. Malacarne 1808 article was published thereafter in the *Giornale della Società di Incoraggiamento*. Malacarne pointed out a metaphor comparing the structure of the human brain with Volta's galvanic pillar.

Therefore, we can assert that between his first researches on the morphology of cerebellum and this article, Malacarne moved from anatomical studies to experimental considerations on the origin of animal electricity.

What kind of experiments did he recommend? What did he want to prove?

As we have already mentioned, Malacarne's physiological theories were always established on anatomical and formal criteria. His anatomical texts cannot be completely separated from his later physiological articles. Indeed, the metaphor used by Malacarne can be correlated with an anatomical parameter, since he compared circumvolutions with galvanic pillars.

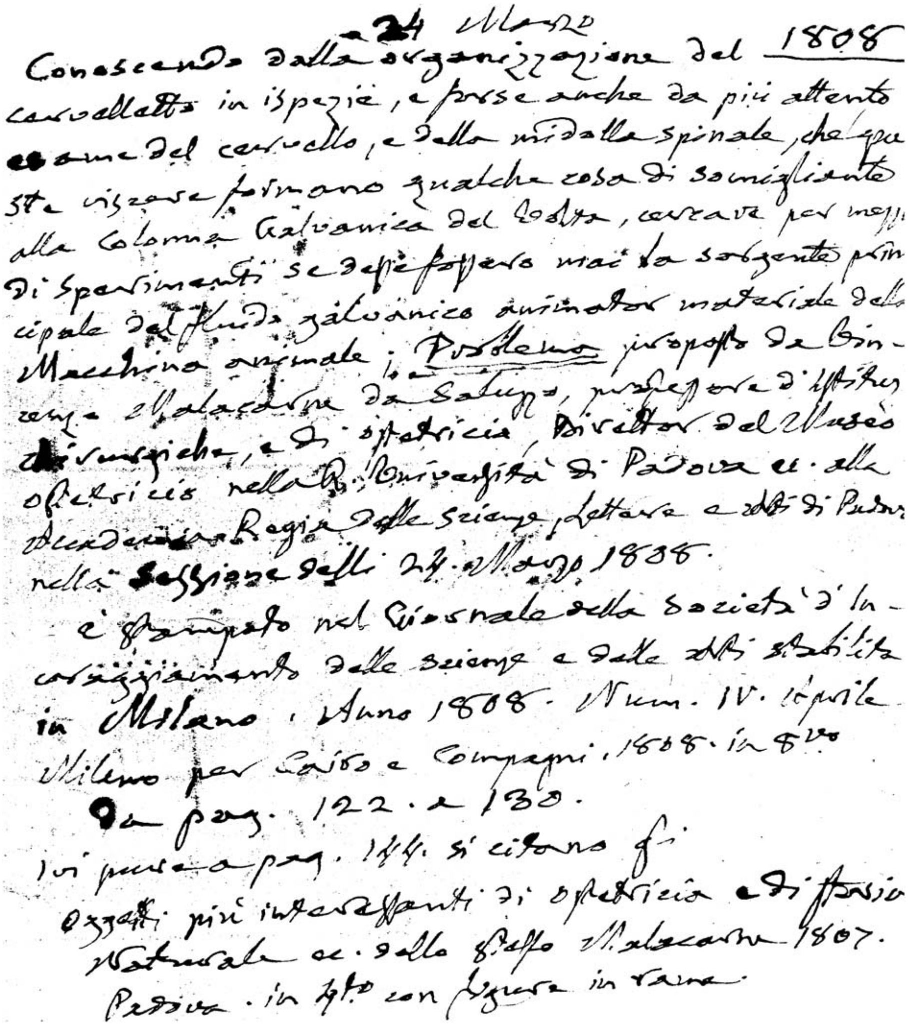

24 Marzo
Conoscendo dalla organizzazione del 1808
cervelletto in ispezie, e forse anche da più attento
esame del cervello, e della midolla spinale, che que-
ste viscere formano qualche cosa di somigliante
alla Colonna Galvanica del Volta, cercare per mezzo
di sperimenti se desse fossero mai la sorgente prin-
cipale del fluido galvanico animator materiale della
Macchina animale; Problema proposto da Vin-
cenzo Malacarne da Saluzzo, professore d'Istitu-
zioni chirurgiche, e di ostetricia, Direttor del Museo
ostetricio nella R. Università di Padova ec. alla
Accademia Regia delle scienze, Lettere e Arti di Padova
nella Sessione delli 24. Marzo 1808.
è stampato nel Giornale della Società d'In-
coraggiamento delle scienze e delle Arti stabilita
in Milano. Anno 1808. Num. IV. Aprile
Milano per Cairo e Compagni. 1808. in 8vo
da pag. 122. a 130.
ivi pure a pag. 144. si citano gli
Oggetti più interessanti di ostetricia e di storia
Naturale ec. dello stesso Malacarne 1807.
Padova. in 4to con figure in rame.

Fig. 3. Malacarne's article written in 1808: *Se il cervello, il cervelletto, la spinal midolla, fors'anche le cartilagini e le ossa della spina formano qualche cosa di simile alla colonna Galvanica del Volta. Problema proposto alla Accademia Reale delle Scienze, Lettere e Arti di Padova*. It concerns human brain electric physiology: Malacarne wished to prove human brain and cerebellum functioned in the same manner as the galvanic battery.

Thus, Malacarne established relations between experimental and physiological studies and his works on the anatomy of the cerebellum:

"*In this book, I had demonstrated how the cerebellum was entirely constituted of medullar lamellae that ascend from medullar cores covered by cortical substance, pushed onto one another, keeping a parallelism in their development: either they go through crosswise or obliquely; or they ascend towards the cerebellar surface; or they descend towards the principal core of the cerebellum, known under the name of the tree of life, or towards the others nine cores described by me in this same part.*" [16]

Therefore, Malacarne kept his anatomopsychological parallelism between lamellar structures and intellectual functions. He correlated it to the possibility to find the origin of the galvanic fluid in brain. He wrote in 1808:

"*My observations communicated to Charles Bonnet allow me to know that we find a number of lamellae proportionally more important in corpse from persons with intellectual faculties, vivacity, with a more exquisite sensibility, a language with a prompter grammar, a sharper intelligence compared to normal persons. Concerning this number found in published tables [. . .], I regret I did not think of adding another* *column indicating the expanse of faculties in persons who I knew before their death. But who can think of all points of views under which we could consider all observations and experiments? Who could think between 1780 and 1789, when I finished my tables, we could apply them to the galvanism?*" [17]

Malacarne added a new interpretation of lamellae's physiological function. He gave a new reading of his casuistry table. A new meaning of cerebellar lamellae is proposed. Here Malacarne's works finds a physiological application in linking the lamellar pattern of cerebellum and the organic origin of animal electricity.

The context of these experiments is fundamental. Indeed after the discoveries of galvanism, all physiologists examined if this fluid could be considered in the animated animal as the motor of nervous system. They also studied if it could be the material origin of the functions of life. Volta's principles showed the identity of galvanic fluid with animal electricity. After they were adopted by European physicists, a role for electric fluid could not be excluded in animal functions that were classically attributed to Descartes' animal spirits or nervous fluid.

This 1808 text was written in this polemical context, in which Malacarne proposed the analogy between the lamellar composition of cerebellum and the pattern of Volta's battery. We can consider this analogy beyond the aspect of patterns. The relations between cerebellar structures and the pattern of Volta's battery may refer to the problem concerning the production of animal electricity. Can we say Malacarne thought animal electricity was produced the same way as in batteries?

Malacarne's analogy of the two patterns of cerebellum and the battery are presented as a question:

"*We suppose six hundred lamellae and we add three hundred lamellae of cerebellum that we observed. We compare to a machine including galvanic pillar and constituted of nine hundred discs, supposing some analogy with the activity [of cerebellum] being able to produce galvanism. Will not we have to see these powerful phenomena that we admire in ourselves, as produced by an unknown prerogative of the cerebral and nervous system?*" [18]

The term *galvanism* here designates animal electricity discovered by Galvani.

We must recall that Malacarne linked the lamellar structure with intellectual faculties as a constant characteristic of animals. Therefore, this conformation could be a causal agent of galvanic phenomena and the expression of the main functions of animal. This anatomical stability in all species could be explained by its physiological role. In the same manner lamellae participate in the functioning of intellectual faculties, lamellae could represent the organic locus of production of animal electricity in all animal species. For many years, the question of the stability of lamellae did not seem a problem for Malacarne, who mentioned it without reference to any functional relevance.

For the first time, Malacarne suggested in his article to lay down the principles of physiological experiments aiming at explaining the stability through all animal species of cerebellar lamellar structures:

"*I must only hereafter publish anatomical results and methods that I have in mind to use during experiments of physics in order to deduce if, yes or no, the cerebellum principally, and perhaps also the brain, must be really considered as a galvanic machine, extended through out all animal species in which we find brain and cerebellum organised in the way verified by me in human, quadrupeds, seal and birds*." [19]

We must stress that Malacarne explained the stability of lamellar structure and considered it a galvanic machine. In other words, animal motility was allowed by the lamellar structures that functioned as a machine. His explanation integrated physiological and intellectual aspects of the role of lamellae in human and animal. He used an economic principle with the purpose of apprehending psychological and physiological phenomena in the same time. Moreover, Malacarne recommended making an organic machine with cerebral parts cut in a disc-like pattern as in batteries. He thought it was possible to record animal electricity provided that anatomist substituted metallic discs by with organic ones:

"*We could experiment on discs from other membranes in the purpose to make comparisons, like membranes from the ox's stomach still warm or from the ventricle of other animals, reducing imperceptibly metallic discs and increasing the number of membranous ones. We shall implement then pieces from dura mater, pia mater, skull of animal still alive or shortly after death. It is true that each beast because of the tiny size of its brain could furnish few discs. Then, we would use a complete cerebellum either covered placed in a cardboard box, or detached of the pia mater. We would use cerebral discs, sometimes mixing human with animal ones to obtain different results*." [20]

This description is of interest because Malacarne previewed the possibility to measure animal electricity in the same way as electricity from battery. We may say he thought about collecting animal electricity in a battery. Indeed, whether he connected brain parts and metallic disc with a battery, he thought to measure an activity. These tests would be the electric expression of animal electricity. He did not recommend to experiment on whole brains connected to a battery. On the contrary, he suggested cutting circular brain pieces with the shape of electric pillars. He also mentioned it was possible to insert cerebral discs between metallic ones. Theoretical recommendations of these experiments are astonishing. Malacarne truly considered animal electricity could be revealed as metallic electricity. He considered branching systems that connect organic and metallic discs. Hence, he thought human and animal brains functioned as a machine producing electricity. In the same way did he envisaged organic functioning and the circulation of electrical currents in a machine.

This issue must be analysed further. Malacarne is not considered by historians of sciences as a materialist. In fact, the physiological model he proposed in 1808 is very close to materialism. Moreover, must we recall that he tried to prove between 1776 and 1794 that the expression of intellectual faculties depended on the number of the lamellae found in internal cerebellar structures. Malacarne may be considered very close to an almost mechanistic materialism, almost mechanist. It seems impossible to understand his 'recordings mode' without considering this. Between 1776 and 1808, Malacarne's thought progressively rejected metaphysics and came closer to mechanistic models.

In spite of all raised issues, a problem persists. Malacarne never mentioned whether he performed his experiments or if he stayed at a purely theoretical level. We believe that Malacarne really made these experiments. As seen in the copy of a commentary of a handwritten draft made by Malacarne in 1808 [21], he asserted that he had probably found Volta's galvanic pillars formed by the organisation of the cerebellum, the brain and the spinal cord. Perhaps, this discovery remained on the level of analogy. Anyhow, he thought these organic points were the main source of the galvanic animate fluid of the animal machine. This annotation can be considered as a report of the conclusions abstracted from his experiments.

Finally, this article contradicts the idea commonly accepted that Malacarne never succeeded in finding a physiological role to brain's circumvolutions. On the contrary, Malacarne assigned them a rational relevance in relation to the circulation and functioning of animal electricity. In 1780, in his *Encefalotomia nuova universale*, he described the cerebral circumvolutions in analogy with intestinal forms and thought it was impossible to assign them a rational signification. He qualified them with terms as *enteroidal folds*. No more did he mention in 1808 these intestinal forms in order to qualify brain circumvolutions. Instead, he unified his theories around the lamellae of cerebellum and brain.

5. Conclusion

At the end of his life, Malacarne contributed to the emergence of a new science, namely electrophysiology. Until his last studies, his thought relied on connections between anatomical forms and physiological functions. Indeed, he made an analogy in 1808 between the lamellar organisation of cerebellum and the form of Volta's battery. In spite of what can be regarded as an anatomophysiological principle, he performed physiological experiments on brain functioning. He tried to record nervous activity characterized by animal electricity. Malacarne's 1808 article can thus be regarded as a contribution to the development of electrophysiology.

Acknowledgements

I would like to thank Jean-Gaël Barbara for proposing me to write this article on my researches on Malacarne's work. I thank the Academy of Sciences of Turin, which provided me with the handwritten documents from the Malacarne funds. I also thank the Public and University Library of Geneva for sending to me a copy of Malacarne's casuistry table.

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