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ЕЖЕМЕСЯЧНЫЙ НАУЧНЫЙ ЖУРНАЛ

Медицинские новости Грузии

საქართველოს სამედიცინო სიახლენი

GEORGIAN MEDICAL NEWS

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GMN: Georgian Medical News is peer-reviewed, published monthly journal committed to promoting the science and art of medicine and the betterment of public health, published by the GMN Editorial Board since 1994. GMN carries original scientific articles on medicine, biology and pharmacy, which are of experimental, theoretical and practical character; publishes original research, reviews, commentaries, editorials, essays, medical news, and correspondence in English and Russian.

GMN is indexed in MEDLINE, SCOPUS, PubMed and VINITI Russian Academy of Sciences. The full text content is available through EBSCO databases.

GMN: Медицинские новости Грузии - ежемесячный рецензируемый научный журнал, издаётся Редакционной коллегией с 1994 года на русском и английском языках в целях поддержки медицинской науки и улучшения здравоохранения. В журнале публикуются оригинальные научные статьи в области медицины, биологии и фармации, статьи обзорного характера, научные сообщения, новости медицины и здравоохранения. Журнал индексируется в MEDLINE, отражён в базе данных SCOPUS, PubMed и ВИНИТИ РАН. Полнотекстовые статьи журнала доступны через БД EBSCO.

GMN: Georgian Medical News – საქართველოს სამედიცინო სიახლენი – არის ყოველთვიური სამეცნიერო სამედიცინო რეცენზირებადი ჟურნალი, გამოიცემა 1994 წლიდან, წარმოადგენს სარედაქციო კოლეგიისა და აშშ-ის მეცნიერების, განათლების, ინდუსტრიის, ხელოვნებისა და ბუნებისმეტყველების საერთაშორისო აკადემიის ერთობლივ გამოცემას. GMN-ში რუსულ და ინგლისურ ენებზე ქვეყნდება ექსპერიმენტული, თეორიული და პრაქტიკული ხასიათის ორიგინალური სამეცნიერო სტატიები მედიცინის, ბიოლოგიისა და ფარმაციის სფეროში, მიმოხილვითი ხასიათის სტატიები.

ჟურნალი ინდექსირებულია MEDLINE-ის საერთაშორისო სისტემაში, ასახულია SCOPUS-ის, PubMed-ის და ВИНИТИ РАН-ის მონაცემთა ბაზებში. სტატიების სრული ტექსტი ხელმისაწვდომია EBSCO-ს მონაცემთა ბაზებიდან.

WEBSITE

www.geomednews.com

К СВЕДЕНИЮ АВТОРОВ!

При направлении статьи в редакцию необходимо соблюдать следующие правила:

1. Статья должна быть представлена в двух экземплярах, на русском или английском языках, напечатанная через **полтора интервала на одной стороне стандартного листа с шириной левого поля в три сантиметра**. Используемый компьютерный шрифт для текста на русском и английском языках - **Times New Roman** (**Кириллица**), для текста на грузинском языке следует использовать **AcadNusx.** Размер шрифта - **12**. К рукописи, напечатанной на компьютере, должен быть приложен CD со статьей.

2. Размер статьи должен быть не менее десяти и не более двадцати страниц машинописи, включая указатель литературы и резюме на английском, русском и грузинском языках.

3. В статье должны быть освещены актуальность данного материала, методы и результаты исследования и их обсуждение.

При представлении в печать научных экспериментальных работ авторы должны указывать вид и количество экспериментальных животных, применявшиеся методы обезболивания и усыпления (в ходе острых опытов).

4. К статье должны быть приложены краткое (на полстраницы) резюме на английском, русском и грузинском языках (включающее следующие разделы: цель исследования, материал и методы, результаты и заключение) и список ключевых слов (key words).

5. Таблицы необходимо представлять в печатной форме. Фотокопии не принимаются. **Все цифровые, итоговые и процентные данные в таблицах должны соответствовать таковым в тексте статьи**. Таблицы и графики должны быть озаглавлены.

6. Фотографии должны быть контрастными, фотокопии с рентгенограмм - в позитивном изображении. Рисунки, чертежи и диаграммы следует озаглавить, пронумеровать и вставить в соответствующее место текста **в tiff формате**.

В подписях к микрофотографиям следует указывать степень увеличения через окуляр или объектив и метод окраски или импрегнации срезов.

7. Фамилии отечественных авторов приводятся в оригинальной транскрипции.

8. При оформлении и направлении статей в журнал МНГ просим авторов соблюдать правила, изложенные в «Единых требованиях к рукописям, представляемым в биомедицинские журналы», принятых Международным комитетом редакторов медицинских журналов - http://www.spinesurgery.ru/files/publish.pdf и http://www.nlm.nih.gov/bsd/uniform_requirements.html
В конце каждой оригинальной статьи приводится библиографический список. В список литературы включаются все материалы, на которые имеются ссылки в тексте. Список составляется в алфавитном порядке и нумеруется. Литературный источник приводится на языке оригинала. В списке литературы сначала приводятся работы, написанные знаками грузинского алфавита, затем кириллицей и латиницей. Ссылки на цитируемые работы в тексте статьи даются в квадратных скобках в виде номера, соответствующего номеру данной работы в списке литературы. Большинство цитированных источников должны быть за последние 5-7 лет.

9. Для получения права на публикацию статья должна иметь от руководителя работы или учреждения визу и сопроводительное отношение, написанные или напечатанные на бланке и заверенные подписью и печатью.

10. В конце статьи должны быть подписи всех авторов, полностью приведены их фамилии, имена и отчества, указаны служебный и домашний номера телефонов и адреса или иные координаты. Количество авторов (соавторов) не должно превышать пяти человек.

11. Редакция оставляет за собой право сокращать и исправлять статьи. Корректура авторам не высылается, вся работа и сверка проводится по авторскому оригиналу.

12. Недопустимо направление в редакцию работ, представленных к печати в иных издательствах или опубликованных в других изданиях.

При нарушении указанных правил статьи не рассматриваются.

REQUIREMENTS

Please note, materials submitted to the Editorial Office Staff are supposed to meet the following requirements:

1. Articles must be provided with a double copy, in English or Russian languages and typed or compu-ter-printed on a single side of standard typing paper, with the left margin of **3** centimeters width, and **1.5** spacing between the lines, typeface - **Times New Roman** (**Cyrillic**), print size - **12** (referring to Georgian and Russian materials). With computer-printed texts please enclose a CD carrying the same file titled with Latin symbols.

2. Size of the article, including index and resume in English, Russian and Georgian languages must be at least 10 pages and not exceed the limit of 20 pages of typed or computer-printed text.

3. Submitted material must include a coverage of a topical subject, research methods, results, and review.

Authors of the scientific-research works must indicate the number of experimental biological species drawn in, list the employed methods of anesthetization and soporific means used during acute tests.

4. Articles must have a short (half page) abstract in English, Russian and Georgian (including the following sections: aim of study, material and methods, results and conclusions) and a list of key words.

5. Tables must be presented in an original typed or computer-printed form, instead of a photocopied version. **Numbers, totals, percentile data on the tables must coincide with those in the texts of the articles.** Tables and graphs must be headed.

6. Photographs are required to be contrasted and must be submitted with doubles. Please number each photograph with a pencil on its back, indicate author's name, title of the article (short version), and mark out its top and bottom parts. Drawings must be accurate, drafts and diagrams drawn in Indian ink (or black ink). Photocopies of the X-ray photographs must be presented in a positive image in **tiff format**.

Accurately numbered subtitles for each illustration must be listed on a separate sheet of paper. In the subtitles for the microphotographs please indicate the ocular and objective lens magnification power, method of coloring or impregnation of the microscopic sections (preparations).

7. Please indicate last names, first and middle initials of the native authors, present names and initials of the foreign authors in the transcription of the original language, enclose in parenthesis corresponding number under which the author is listed in the reference materials.

8. Please follow guidance offered to authors by The International Committee of Medical Journal Editors guidance in its Uniform Requirements for Manuscripts Submitted to Biomedical Journals publication available online at: http://www.nlm.nih.gov/bsd/uniform_requirements.html
http://www.icmje.org/urm_full.pdf
In GMN style for each work cited in the text, a bibliographic reference is given, and this is located at the end of the article under the title "References". All references cited in the text must be listed. The list of references should be arranged alphabetically and then numbered. References are numbered in the text [numbers in square brackets] and in the reference list and numbers are repeated throughout the text as needed. The bibliographic description is given in the language of publication (citations in Georgian script are followed by Cyrillic and Latin).

9. To obtain the rights of publication articles must be accompanied by a visa from the project instructor or the establishment, where the work has been performed, and a reference letter, both written or typed on a special signed form, certified by a stamp or a seal.

10. Articles must be signed by all of the authors at the end, and they must be provided with a list of full names, office and home phone numbers and addresses or other non-office locations where the authors could be reached. The number of the authors (co-authors) must not exceed the limit of 5 people.

11. Editorial Staff reserves the rights to cut down in size and correct the articles. Proof-sheets are not sent out to the authors. The entire editorial and collation work is performed according to the author's original text.

12. Sending in the works that have already been assigned to the press by other Editorial Staffs or have been printed by other publishers is not permissible.

Articles that Fail to Meet the Aforementioned Requirements are not Assigned to be Reviewed.

ავტორთა საყურადღებოდ!

რედაქციაში სტატიის წარმოდგენისას საჭიროა დავიცვათ შემდეგი წესები:

1. სტატია უნდა წარმოადგინოთ 2 ცალად, რუსულ ან ინგლისურ ენებზე,დაბეჭდილი სტანდარტული ფურცლის 1 გვერდზე, 3 სმ სიგანის მარცხენა ველისა და სტრიქონებს შორის 1,5 ინტერვალის დაცვით. გამოყენებული კომპიუტერული შრიფტი რუსულ და ინგლისურენოვან ტექსტებში - **Times New Roman (Кириллица)**, ხოლო ქართულენოვან ტექსტში საჭიროა გამოვიყენოთ **AcadNusx.** შრიფტის ზომა – 12. სტატიას თან უნდა ახლდეს CD სტატიით.

2. სტატიის მოცულობა არ უნდა შეადგენდეს 10 გვერდზე ნაკლებს და 20 გვერდზე მეტს ლიტერატურის სიის და რეზიუმეების (ინგლისურ, რუსულ და ქართულ ენებზე) ჩათვლით.

3. სტატიაში საჭიროა გაშუქდეს: საკითხის აქტუალობა; კვლევის მიზანი; საკვლევი მასალა და გამოყენებული მეთოდები; მიღებული შედეგები და მათი განსჯა. ექსპერიმენტული ხასიათის სტატიების წარმოდგენისას ავტორებმა უნდა მიუთითონ საექსპერიმენტო ცხოველების სახეობა და რაოდენობა; გაუტკივარებისა და დაძინების მეთოდები (მწვავე ცდების პირობებში).

4. სტატიას თან უნდა ახლდეს რეზიუმე ინგლისურ, რუსულ და ქართულ ენებზე არანაკლებ ნახევარი გვერდის მოცულობისა (სათაურის, ავტორების, დაწესებულების მითითებით და უნდა შეიცავდეს შემდეგ განყოფილებებს: მიზანი, მასალა და მეთოდები, შედეგები და დასკვნები; ტექსტუალური ნაწილი არ უნდა იყოს 15 სტრიქონზე ნაკლები) და საკვანძო სიტყვების ჩამონათვალი (key words).

5. ცხრილები საჭიროა წარმოადგინოთ ნაბეჭდი სახით. ყველა ციფრული, შემაჯამებელი და პროცენტული მონაცემები უნდა შეესაბამებოდეს ტექსტში მოყვანილს.

6. ფოტოსურათები უნდა იყოს კონტრასტული; სურათები, ნახაზები, დიაგრამები - დასათაურებული, დანომრილი და სათანადო ადგილას ჩასმული. რენტგენოგრამების ფოტოასლები წარმოადგინეთ პოზიტიური გამოსახულებით **tiff** ფორმატში. მიკროფოტოსურათების წარწერებში საჭიროა მიუთითოთ ოკულარის ან ობიექტივის საშუალებით გადიდების ხარისხი, ანათალების შეღებვის ან იმპრეგნაციის მეთოდი და აღნიშნოთ სურათის ზედა და ქვედა ნაწილები.

7. სამამულო ავტორების გვარები სტატიაში აღინიშნება ინიციალების თანდართვით, უცხოურისა – უცხოური ტრანსკრიპციით.

8. სტატიას თან უნდა ახლდეს ავტორის მიერ გამოყენებული სამამულო და უცხოური შრომების ბიბლიოგრაფიული სია (ბოლო 5-8 წლის სიღრმით). ანბანური წყობით წარმოდგენილ ბიბლიოგრაფიულ სიაში მიუთითეთ ჯერ სამამულო, შემდეგ უცხოელი ავტორები (გვარი, ინიციალები, სტატიის სათაური, ჟურნალის დასახელება, გამოცემის ადგილი, წელი, ჟურნალის №, პირველი და ბოლო გვერდები). მონოგრაფიის შემთხვევაში მიუთითეთ გამოცემის წელი, ადგილი და გვერდების საერთო რაოდენობა. ტექსტში კვადრატულ ფჩხილებში უნდა მიუთითოთ ავტორის შესაბამისი N ლიტერატურის სიის მიხედვით. მიზანშეწონილია, რომ ციტირებული წყაროების უმეტესი ნაწილი იყოს 5-6 წლის სიღრმის.

9. სტატიას თან უნდა ახლდეს: ა) დაწესებულების ან სამეცნიერო ხელმძღვანელის წარდგინება, დამოწმებული ხელმოწერითა და ბეჭდით; ბ) დარგის სპეციალისტის დამოწმებული რეცენზია, რომელშიც მითითებული იქნება საკითხის აქტუალობა, მასალის საკმაობა, მეთოდის სანდოობა, შედეგების სამეცნიერო-პრაქტიკული მნიშვნელობა.

10. სტატიის ბოლოს საჭიროა ყველა ავტორის ხელმოწერა, რომელთა რაოდენობა არ უნდა აღემატებოდეს 5-ს.

11. რედაქცია იტოვებს უფლებას შეასწოროს სტატია. ტექსტზე მუშაობა და შეჯერება ხდება საავტორო ორიგინალის მიხედვით.

12. დაუშვებელია რედაქციაში ისეთი სტატიის წარდგენა, რომელიც დასაბეჭდად წარდგენილი იყო სხვა რედაქციაში ან გამოქვეყნებული იყო სხვა გამოცემებში.

აღნიშნული წესების დარღვევის შემთხვევაში სტატიები არ განიხილება.

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No 2 (359) 2025

Содержание:

Gavrilova Uliana V, Alieva Samaya A, Gerasimenko Aleksandra A, Mikhaleva Ekaterina A, Solovieva Ekaterina V, Vedzizheva Khava Kh, Sadykov Magomed L, Belousova Anastasia A, Ladaev Abubakar Kh, Aupov Ibragim A, Maasheva Elita A, Makhamaev Ilias B, Yanarkaev Ibragim R.
NEXT-GENERATION ANTIOXIDANTS: SHOULD WE TARGET PEROXIREDOXINS (PRX)?…….....……..6-14

Marina Endeladze, Maia Zhamutashvili, Tinatin Gognadze, Elene Meskhi, Natia Jojua, M. Akhvlediani.
CASE REPORT OF CAT SCRATCH DISEASE (BARTONELLA)…….....……..15-17

Karapetyan A.G, Santini C, Pellei M, Caviglia M, Dallakyan A.M, Petrosyan Zh.H, Danielyan M.H, Nebogova K.A, Grigoryan V.S.
MANIFESTATION OF RADIOPROTECTIVE PROPERTIES IN COPPER COMPLEXES $[CU(L^{CF3})_2]$ AND $[CU(ADM)(PPH_3)_2]PF_6$..…18-22

Nato Nakudashvili, Levan Ratiani, Tamar Megrelishvili, Elene Saribekovi, Marine Tsabadze, Nina Kipiani, Nino Intskirveli, Magda Tortladze, Tea Gabunia, Shorena Tsiklauri, Zaza Nakudashvili, George Ormotsadzr, Tamar Sanikidze.
FEATURES OF VASOMOTOR RHINITIS (VMR) IN PATIENTS WITH A HISTORY OF COVID-19 INFECTION…….....…….23-31

Warda Mohamed, Rashid Eltayeb, Hussam Ali Osman, Mosab Omer, Elryah. I. Ali, Ammar Abdelmola, Tagwa Yousif, Mohamed Belhocine, Safa Taha, Elyasa Elfaki, Wael Alzahrani, Asaad Babker, Abdelgadir Elamin Eltom, Marwan Ismail, Ayman Alfeel.
BIOCHEMICAL INSIGHTS AND HORMONAL MARKERS OF POLYCYSTIC OVARY SYNDROME IN SUDANESE WOMEN: EXPLORING INFERTILITY AND RISK FACTORS IN RED SEA STATE…….....…….32-39

Kolupayev S.M, Goloborodko M.M, Bytiak S.Yu, Lavrinenko A.S, Lupyr M, Lantukh I.V, Lytvynova I.L, Gulbs O.A, Dikhtyarenko S.Yu, Kobets O.V.
PSYCHOLOGICAL FEATURES OF THE REHABILITATION OF PERSONS WITH UROLITHIASIS…….....……40-44

Wang-Yong Li, Xiao-Yan Yang, Zhun Cai, Guo-Fu Chen.
A CASE OF CECAL CANCER WITH RETROPERITONEAL ABSCESS…….....……45-48

Tamriko Dzotsenidze, Arsen Gvenetadze, Giorgi Burkadze, Ekaterine Isakidi, Mariam Shulaia.
GENETIC ALTERATIONS IN TUBO-OVARIAN EPITHELIUM DURING OVARIAN NEOPLASIA…….....…49-54

Ali M. Muhammed Ali, Omar M. Yahya, Ehsan HT. AlDabbagh.
IN SILICO DOCKING OF SILYMARIN ACTIVE CONSTITUENTS WITH INSULIN RECEPTORS: A STEP TOWARD DIABETES THERAPEUTICS…….....……..55-62

Armenuhi Avagyan, Taline K. Ashekian, Armenuhi Snkhchyan, Hasmik Mkrtchyan, Tigran Petrosyan.
BARRIERS AND SOLUTIONS IN THE USE OF ALTERNATIVE AND AUGMENTATIVE COMMUNICATION: A PILOT DESCRIPTIVE STUDY PRESENTING INSIGHTS FROM ARMENIAN PROFESSIONALS…….....……63-71

Xin-Juan Wang, Lian-Ping He.
STATISTICAL TEACHING ON BUILDING STROKE PREDICTION MODELS…….....……72-75

Kosherova Bakhyt Nurgaliyevna, Abbozova Shakhnosa Maratovna, Smagul Manar Asyrovna, Zhumagaliyeva Galina Dautovna, Sagyndykova Togzhan Baibolsynovna.
MEASLES IN PREGNANCY IN THE REPUBLIC OF KAZAKHSTAN: CLINICAL AND LABORATORY MANIFESTATIONS AND OUTCOMES…….....……..76-80

Warda Mohamed, Rashid Eltayeb, Hussam Ali Osman, Mosab Omer, Elryah. I. Ali, Ammar Abdelmola, Tagwa Yousif, Mohamed Belhocine, Safa Taha, Elyasa Elfaki, Wael Alzahrani, Ayman Alfeel, Asaad Babker, Abdelgadir Elamin Eltom, Marwan Ismail.
FOLLICLE-STIMULATING HORMONE RECEPTOR MUTATIONS IN SUDANESE WOMEN: A STUDY ON POLYCYSTIC OVARY SYNDROME…….....……81-86

Saidulaev M.A, Osipova N.I, Gurtskaya A.D, Semov N.D, Khusainov R.R, Khabarov E.A, Lech D.S, Stotland P.A, Eloeva V.V, Syromyatnikova A.V.
PIRACETAM HELPS RESTORE VISION AFTER CRANIOCEREBRAL TRAUMA…….....……87-88

Ming Li, Wen-Wen Hao, Li-Juan Ru.
THE ASSOCIATION BETWEEN AQUEOUS HUMOR MICROENVIRONMENT IN DIABETIC CATARACT PATIENTS AND POSTOPERATIVE MACULAR EDEMA AND VISUAL ACUITY CHANGES…….....……..89-90

Voloshyn-Haponov I.K, Lantukh I.V, Gulbs O.A, Dikhtyarenko S.Yu, Kobets O.V, Pustova N.O, Popova N.G, Gridneva O.V, Ostapenko V.M, Mikhanovska N.G, Torianyk I.I.
PSYCHOLOGICAL FEATURES OF THE SUBJECTIVE PERCEPTION OF THE QUALITY OF LIFE OF PATIENTS WITH HEPATOCEREBRALDYSTROPHY…….....……91-95

Bangqiang Hou, Wei Liu, Ke Pan, Yiya Wang, Yaomin Luo, Yutong Han, Jingjing Liu, Qing Wu, Yinxu Wang.
BRAIN NETWORK FUNCTIONAL CONNECTIVITY AND CORTICAL ACTIVATION FEATURES DURING THE SWALLOWING TASK FOR THE PATIENTS OF POST STROKE DYSPHAGIA: A MULTI- CHANNEL FNIRS STUDY…….....96-107

Assel Ibrayeva, Dinara Ospanova, Korlan Saduakasova, Anar Akshalova, Anar Muratbayeva, Shynar Tanabayeva, Ildar Fakhradiyev.
PREVALENCE AND SOCIO-DEMOGRAPHIC RISK FACTORS OF EMOTIONAL BURNOUT AMONG PSYCHIATRISTS AND NURSING STAFF IN PSYCHIATRIC SERVICES IN KAZAKHSTAN…….....……...108-115

Violeta Grajçevci Uka, Art Uka, Lirim Isufi.
THE SOCIODEMOGRAPHICAL AND MORPHOLOGICAL CHARACTERISTICS OF PRESCHOOL CHILDREN WITH SIDEROPENIC ANEMIA IN THE KOSOVO SAMPLE…….....……..……116-119

Li-Bo Wang, Chun-Miao Xu.
ENHANCING OPHTHALMIC NURSING EDUCATION: A COMPREHENSIVE APPROACH TO CLINICAL TEACHING AND TRAINING…….....……..……..120-122

Maia Zhamutashvili, Tinatin Gognadze, Natia Jojua, Elene Meskhi, Ketevan Meskhi, Ekaterine Dolmazashvili.
CO-OCCURRENCE OF HANTAVIRUS PULMONARY SYNDROME AND HEMORRHAGIC FEVER WITH RENAL SYNDROME.....123-125

Abdukalikova D.B, Auezova A.M, Baymuratova M.A, Yessembayeva S.S, Yermukhanova G.T, Yerkibayeva ZH.U.
WORKSHOP AS A PRACTICE-ORIENTED METHOD OF TEACHING DENTISTS: INTRODUCTION TO EDUCATIONAL PROGRAMS FOR WORKING WITH CHILDREN WITH AUTISM SPECTRUM DISORDERS (ASD)….……126-132

Li-Juan Ru, Qian-Qian Yao, Ming Li.
RISK PREDICTION MODEL FOR ACUTE KIDNEY INJURY IN PATIENTS WITH SEVERE ACUTE PANCREATITIS…….....….133-135

Sawer S. Ahmed, Abdulazeez M. Brifkani, Haval J. Ali, Nasir A. Al Allawi.
FACTORS AFFECTING HEALTH RELATED QUALITY OF LIFE IN ADULT PATIENTS WITH BETA-THALASSEMIA MAJOR…….....136-142

Liu-Xia Shi, Xiao-Ya Peng, Xiao-Xu Ruan, Rui Li, Wen-Jie Wen, Chao Deng.
WHOLE TRANSCRIPTOME SEQUENCING AND CIRC_HSA_0001847 ON PROLIFERATION AND INVASION OF ORAL SQUAMOUS CELLCARCINOMA…….....……143-155

Takuma Hayashi, Krishna Prasad Acharya, Sarita Phuyal, Ikuo Konishi.
THE ROLE OF LIVE BIRD MARKETS SHOULD BE EMPHASIZED IN PREVENTING THE SPREAD OF HIGHLY PATHOGENIC AVIANINFLUENZAINFECTIONS…….....……156-158

Karapetyan A.G, Grigoryan V.S, Santini C, Pellei M, Del Gobbo J, Dallakyan A.M, Petrosyan Zh.H, Fanarjyan S.A, Danielyan M.H, Nebogova K.A.
BLOOD AND CYTOGENETIC MARKERS IN EXPERIMENTAL BURNS AND THEIR TREATMENT WITH [CU(L^{CF3})$_2$] AND [CU(ADM)(PPH_3)$_2$]PF_6…….....……..159-163

Sharofova M.U, Khalimova F.T, Habasi Maidina, Jiangyu Zhao, Haji Akber Aisa.
ANTIMICROBIAL AND ANTI-INFLAMMATORY ACTIVITY OF PLANT EXTRACTS: PROSPECTS FOR THE DEVELOPMENT OF COMBINEDTHERAPEUTICAGENTS…….....……..164-168

GEORGIAN MEDICAL NEWS
No 2 (359) 2025

BRAIN NETWORK FUNCTIONAL CONNECTIVITY AND CORTICAL ACTIVATION FEATURES DURING THE SWALLOWING TASK FOR THE PATIENTS OF POST STROKE DYSPHAGIA: A MULTI- CHANNEL FNIRS STUDY

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Abstract.

Background: Functional near-infrared spectroscopy (fNIRS), as an emerging non-invasive brain imaging technique, provides new perspectives to study the functional brain connectivity in Post stroke dysphagia (PSD) patients.

Objective: Using the fNIRS technique to observe and compare the differences in brain network functional connectivity and activation between healthy subjects and PSD patients during the performance of a swallowing task and provide new insights into the mechanisms and treatment of PSD.

Methods: A total of 26 healthy volunteers (Healthy control, HC) and 53 PSD patients were enrolled in this study, then PSD patients were then divided into two groups: PSD hemorrhagic (PSD(H)) group and PSD ischemic (PSD(I)). The fNIRS technique was used to collect the swallowing task state data. Brain regions closely related to swallowing function were selected as regions of interest (ROI). The strength of brain network functional connectivity and the degree of brain area activation in the swallowing task were analysed in each group, and correlation analyses and ROC curve analyses were performed with clinical assessment indicators.

Results: The PSD group showed a significant reduction ($p<0.05$) in brain network functional connectivity strength in swallowing-related brain regions compared to the HC group, and there was no significant difference between the PSD(H) and PSD(I) group. On specific channels, the PSD group showed a significant reduction ($p<0.05$) in brain network functional connectivity strength compared to the HC group. Furthermore, the strength of swallowing-related cortical brain functional connectivity was correlated with swallowing function severity in PSD patients. The critical value of the functional connectivity is expected to be an indicator for assessing whether PSD patients are dependent on tube feeding.

Conclusion: The present study reveals diminished functional connectivity and abnormal activation patterns of brain networks in PSD patients during a swallowing task, providing new evidence for the mechanisms of PSD and potential neuromodulatory targets.

Key words. Stroke, dysphagia, functional near-infrared spectroscopy, brain network functional connectivity.

Introduction.

According to statistics, 50-80% of stroke patients suffer from various degrees of swallowing dysfunction [1,2]. Post stroke dysphagia (PSD) not only prolongs the hospital stay and increases medical costs but also may lead to serious complications such as malnutrition, dehydration, aspiration pneumonia, etc., which significantly increase the morbidity, mortality, and re-admission rates of patients [3]. In addition, PSD has a serious impact on the quality of patients' daily life, which brings heavy psychological and economic burdens to patients and their families. The mechanism of PSD has not been fully elucidated, and the current treatments include, but are not limited to, conventional swallowing training, motor-behavioural therapy, catheter balloon dilatation, traditional Chinese medicine, physical factor therapy, and non-invasive neuromodulation techniques [4], which can achieve certain therapeutic effects but often encounter bottlenecks. Therefore, in-depth investigation of the mechanism of PSD and searching for potential intervention targets are of great significance to improve the clinical efficacy of PSD.

Functional near-infrared spectroscopy (fNIRS), as a novel non-invasive neurological detection technique, can monitor real-time changes in cerebral cortex oxyhemoglobin (HbO_2) and reduced hemoglobin (HbR) changes in the cerebral cortex, indirectly reflecting local changes in brain functional activity [5]. Compared with functional magnetic resonance imaging (fMRI), fNIRS has obvious advantages in terms of device portability, operability, low cost and high temporal resolution [6,7]. In recent years, fNIRS has been widely used in the field of stroke rehabilitation research, especially in cognitive and speech functions, but relatively few studies have been conducted on PSD, which suggests that the potential for the application of fNIRS in the field of PSD has not been fully explored [8].

The aim of this study was to investigate the differences in brain network functional connectivity strength and brain area activation strength between PSD patients and healthy controls during the performance of swallowing tasks using fNIRS technology, to provide new ideas for the exploration of the rehabilitation mechanism and the selection of neuromodulation targets for PSD patients.

Materials and Methods.

Participants: This observational study aimed to investigate the neural mechanisms of PSD, which was filed through the China Clinical Trial Registry (registration number: ChiCTR2400083503) and approved by the Medical Ethics Committee of the Affiliated Hospital of Chuanbei Medical College (approval number: 2024ER9-1). All participants signed a written informed consent form before participating in the study. The research team strictly followed the established inclusion and exclusion criteria to ensure the rigour of the study

and the accuracy of the data. The study population was divided into two groups: healthy adults as the control group (Healthy control, HC), and patients with PSD as the experimental group.

Screening criteria for healthy controls (HC).

Inclusion criteria:

(1)Age ≥ 18 years.

(2)No significant visual or hearing impairment.

(3)A score of 27 or more on the Mini-Mental State Examination (MMSE).

Exclusion criteria:

(1)Past or present diagnosis of gastro-oesophageal reflux, abnormal laryngeal sensation, dysphagia, oral motor dysfunction, neurological dysfunction.

(2)Previous or current diagnosis of brain injury, epilepsy, neck injury, mental illness, etc.

Screening criteria for patients with PSD.

Inclusion criteria:

(1)Stroke is diagnosed by computed tomography (CT) or magnetic resonance imaging (MRI) [9].

(2)The first onset of the disease is between 2 weeks and 6 months.

(3)Age ≥ 18 years.

(4)The presence of swallowing dysfunction was confirmed by Flexible Endoscopic Evaluation of Swallowing (FEES).

Exclusion criteria:

(1)Swallowing dysfunction caused by other neurological disorders, including Parkinson's disease, Alzheimer's disease, motor neurone disease, craniocerebral trauma, and cerebellar or brainstem strokes.

(2)Pregnancy status.

(3)Vital signs are unstable or in the acute phase of the disease.

(4)Insufficient cognitive functioning to cooperate with the FEES, fNIRS examination and swallowing scale assessment.

Measurement tasks and implementation methods.

Prior to the assessment, basic information of all subjects was collected, including name, gender, age at baseline, symptoms, time of onset, stroke site, current medical history, past medical history, family history of genetic disorders, previous treatments, imaging findings and medications. Swallowing function assessment of patients with PSD: The assessment was performed by using the FEES, the standardised swallowing assessment (SSA) and functional oral intake scale (FOIS).

FESS is an important clinical modality for assessing swallowing function, and together with the videofluroscopic swallowing study (VFSS), it is considered the "gold standard" for clinical assessment of swallowing function [10]. The FEES can provide a better view of the pharynx and secretion retention by allowing patients to swallow food pellets of different viscosities and has a high sensitivity for residue detection, and can observe the speed of swallowing initiation, pharyngeal residue after swallowing, the ability to remove food pellets, and the degree of aspiration.

SSA:

The SSA has been shown to have high specificity, sensitivity, good validity and reliability and is suitable for clinical application [11]. The scale is divided into 3 parts: clinical examination, 5 mL water swallow test (repeated 3 times), and 60 mL water one-time swallow test. The total SSA score ranges from 18 to 46, with higher scores indicating poorer swallowing function.

FOIS:

According to the patient's eating situation, FOIS classifies swallowing function into grades 1 to 7, with higher scores having better swallowing function, and grade 7 indicating complete oral feeding without restriction [12].

fNIRS task state acquisition:

In this study, the 63-channel fNIRS imaging device NirSmart (NirScan Danyang Huichuang Medical Equipment Co. Ltd., China) was used to acquire data from subjects in the swallowing task state. The right motor cortex (RMC) left motor cortex (LMC), right sensory cortex (RSC), left sensory cortex (LSC), right supplementary motor area (RSMA), Left supplementary motor area (LSMA), Right prefrontal cortex (RPFC), Left prefrontal cortex (LPFC) and Left prefrontal cortex (LPFC) as regions of interest (ROI) (Figure 1A) [13]. Prior to the measurements, all subjects were trained to perform the swallowing task correctly and were aware of the need to sit relaxed and still, avoid moving and thinking, and ensure that there were no other non-instructional movements during the measurements. Upon entering the fNIRS assessment room, subjects sat comfortably for 5 min before putting on the fNIRS head cap and completing the swallowing task of either imagining a drink of water or performing a drink of water. the task paradigm was designed in a block format (5 swallowing actions and 5 resting task blocks), with each task block lasting 35s. There was a 10s preparation time at the beginning of the task to ensure data stability, and a total of 175 s was required to complete the task. the specific paradigm See Figure 1B.

fNIRS data processing:

The fNIRS swallowing task state data preprocessing was run using the NirSpark toolkit software, with the signal standard deviation threshold set to 6 and the peak threshold set to 0.5, and motion artefacts were identified and removed using spline interpolation. General noise including heartbeat, respiration, and Mel waves were filtered using bandpass filtering at 0.01-0.1 Hz. The path difference factor was set to -6-6, and the real-time concentration changes of HbO_2 and HbR in the task state of the subjects were calculated according to the modified Beer-Lamber law, and the HbO_2 with a better signal-to-noise ratio was used as the main index in this study [14].

Changes in cortical HbO_2 concentration in subjects at each time point were extracted in the Network module of NirSpark and analysed for Pearson's correlation coefficients of HbO_2 levels in each channel on the time series. The FisherZ transformation was then performed, and the transformed values were defined as the strength of functional connectivity between channels. Block average analysis, linear correction and eigenvalue (mean) analysis were performed in the BlockAvg module of NirSpark for the imagined drinking or water task to calculate the change in blood oxygen concentration for a single channel over that time window. The degree of correlation between the blood oxygen change and the temporal task was analysed using

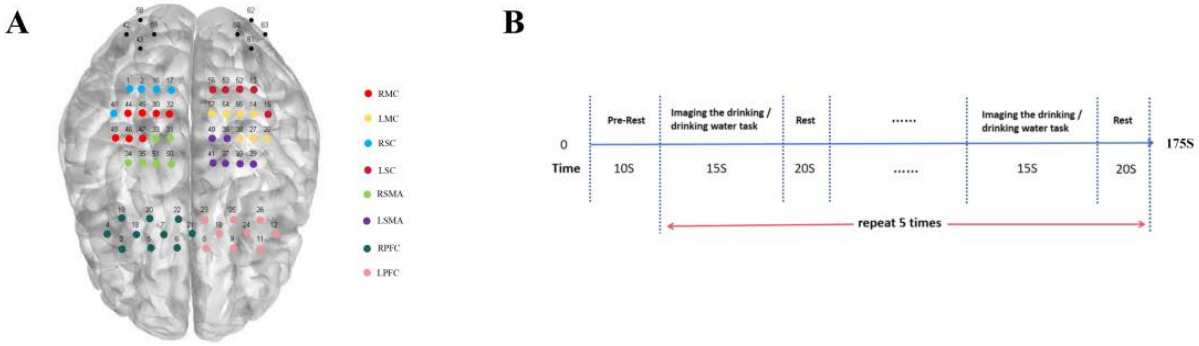

Figure 1. *(A) Correspondence between fNIRS acquisition headcaps and brain networks. (B) Imaging the drinking /drinking water task paradigm. RMC: Right Motor Cortex; LMC: Left Motor Cortex; RSC: Right Sensory Cortex; LSC: Left Sensory Cortex; RSMA: Right Supplementary Motor Area; LSMA: Left Motor Cortex; LMC: Left Motor Cortex; RSC: Right Sensory Cortex; LSC: Left Sensory Cortex; RSMA: Right Supplementary Motor Area; LSMA: Left RSMA: Right Supplementary Motor Area; LSMA: Left Supplementary Motor Area; Right Prefrontal Cortex: RPFC; Left Prefrontal Cortex: LPFC.*

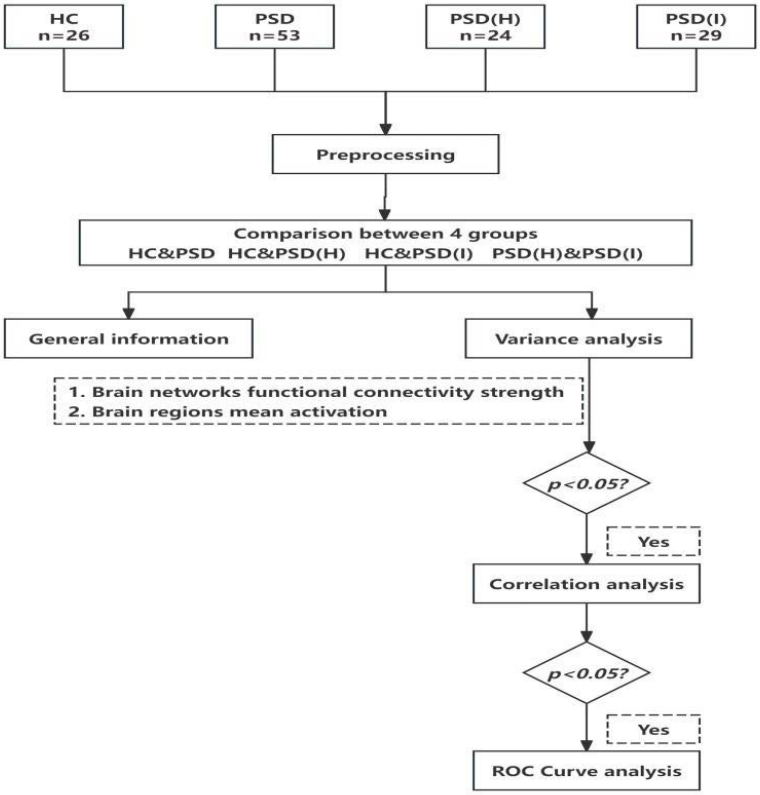

Figure 2. *The flowchart for the data analysis. HC group: Healthy control group. PSD group: Post Stroke Dysphagia group. PSD(H): PSD Hemorrhagic group; PSD(I): PSD Ischemic group.*

a general linear model (GLM), and the matrix was designed using the hemodynamic response function (HRF) as the basis function, removing the baseline drift, and short-term correlation of high-frequency noises, such as heartbeat and respiration, was correction, and defining the transformed value as the degree of activation of the channel.

Statistical analyses:

Statistical analyses were performed using SPSS 27.0 (IBM Corp., NY, USA). Graphs were generated using the NirSpark package, GraphPad PRISM Version 8.0.1 (GraphPad Software - San Diego, CA, USA) software. Descriptive statistics were presented as mean±standard deviation ($\bar{x}$ ± s) or median (interquartile range), i.e., Md (P25, P75).; Comparisons of general information, brain network functional connectivity and brain region activation among the 4 groups were performed using one-way analysis of variance (One-way ANOVA), non-parametric Kruskal-Wallis test with Dunn's post-hoc test. Correlation analysis was performed using Spearman's method, with a significance threshold of $p<0.05$. Finally, ROC curves were plotted, and the area under the curve, sensitivity and specificity were calculated, with the functional connectivity strength corresponding to the maximum Yoden's index as the optimal threshold value. The flow chart is shown in Figure 2.

Results.

Demographic and clinical characteristics:

A total of 29 healthy adult subjects and 58 patients with PSD were recruited for fNIRS data acquisition. 3 healthy adult subjects and 5 patients with PSD were excluded due to excessive subject motion tailing and signal quality. Twenty-six healthy adult subjects and 53 PSD patients were finally included, and the PSD group was divided into PSD(H) group and PSD(I) group according to the etiology. Compared with the HC group, there were no significant differences in age and gender in the PSD group ($p>0.05$); compared with the PSD(H) group, there were no statistically significant differences in age, gender, stroke site (left/right), SSA score and FOIS score in the PSD(I) group ($p>0.05$, see Table 2).

Characteristics and differences in average functional connectivity strength of brain networks:

Compared with the HC group (Mean=0.467, SD=0.170), the mean functional connectivity strength of the brain networks of the swallowing-related cortex in the PSD group (Mean=0.306, SD=0.122), the PSD(H) group (Mean=0.303, SD=0.119) and the PSD(I) group (Mean=0.307, SD=0.133) were decreased (Figure 3A-D), and the difference was statistically significant ($p<0.05$, see Figure 3E).The mean functional connectivity strength of brain networks in PSD(I) group was higher than that in PSD(H) group, but the difference was not statistically significant ($p>0.05$, see Figure 3E).

Characteristics and differences in functional connectivity strength across brain networks:

Compared with the HC group, the PSD, PSD(H) and PSD(I) groups showed a significant decrease in the functional connectivity strengths of homologous and heterologous brain networks of the eight swallowing cortex brain networks in the RMC, LMC, RSC, LSC, RSMA, LSMA, RPFC and LPFC ($p<0.05$, see Figure 4A-C), while no significant difference in the functional connectivity strengths of homologous and heterologous brain networks was observed between PSD(H) and PSD(I) groups ($p>0.05$, see Figure 4D).

Characteristics and differences in average activation levels in brain regions:

Characteristic maps of activation in each brain region during the swallowing task for subjects in the HC, PSD, PSD(H) and PSD(I) groups are shown in Figure 5A-D. Compared with the HC group, the average activation in the swallowing brain regions of the PSD, PSD(H) and PSD(I) groups tended to be decreasing (Figure 5E-G), and the average activation level of swallowing brain area was slightly increased in the PSD(I) group compared with the PSD(H) group (Figure 5H).

Characteristics and Differences in Mean Activation Levels across Brain Regions:

Analysing the activation characteristics of the brain regions during the swallowing task in the four groups, it was found that the PSD, PSD(H) and PSD(I) groups showed a decreasing trend in the activation intensity of the brain regions compared to the HC group. Compared with the HC group, the PSD group showed statistically significant differences in channel 11 (S5- D4), 12 (S5-D10), 44 (S17-D1) and 45 (S17-D12); PSD(H) group showed statistically significant differences in channel 11 (S5-D4); and PSD(I) group showed statistically significant differences in channels 11 (S5-D4), 12 (S5-D10) and 44 (S17-D1) were statistically significant ($p<0.05$, see Figure 6A,B,C; Table 3); there was no significant difference in activation in all brain regions between PSD(H) and PSD(I) groups ($p>0.05$, see Figure 6D; Table 3).

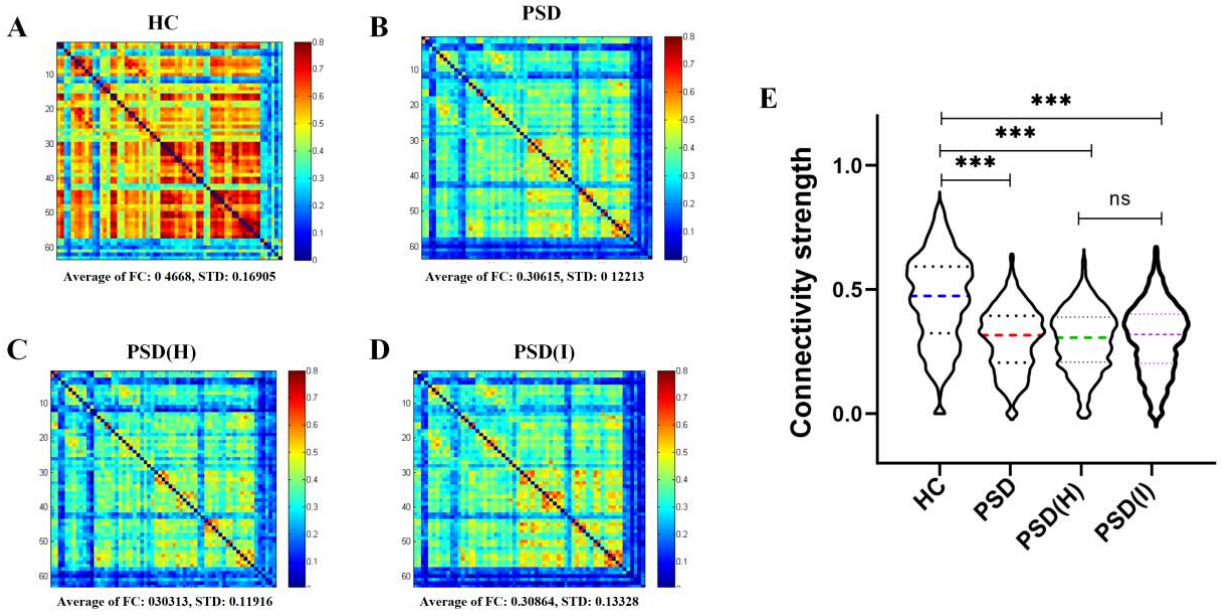

Figure 3. *Brain functional connectivity strength differences (A,B,C,D). HC group: Healthy control group; PSD group: Post Stroke Dysphagia group; (C) PSD (H): PSD Hemorrhagic group; PSD(I): PSD Ischemic group. (E) Analysis of variances. (Updated "Average of FC" to "Average of FC" in Figure 3ABC).*

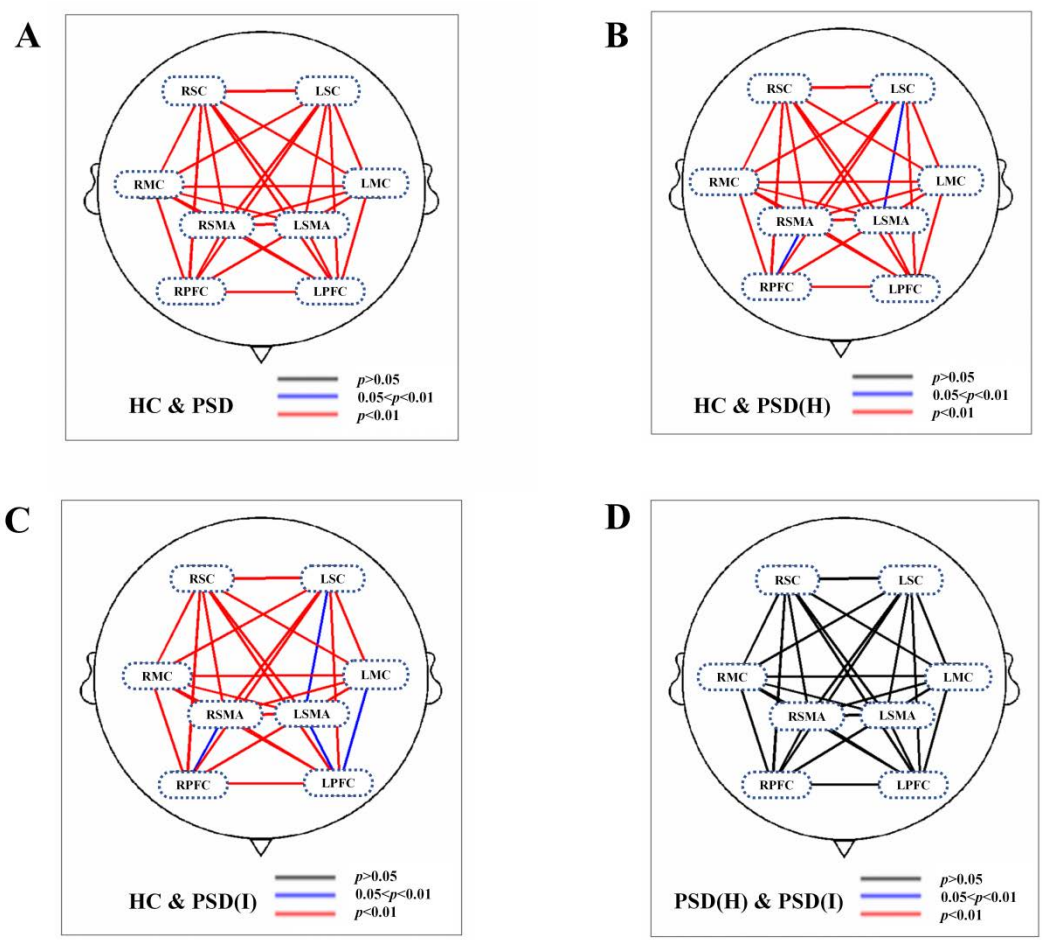

Figure 4. *Brain network connectivity differences (A,B,C,D). HC group: Healthy control group; PSD group: Post Stroke Dysphagia group; PSD(H): PSD Hemorrhagic group; PSD(I): PSD Ischemic group.*

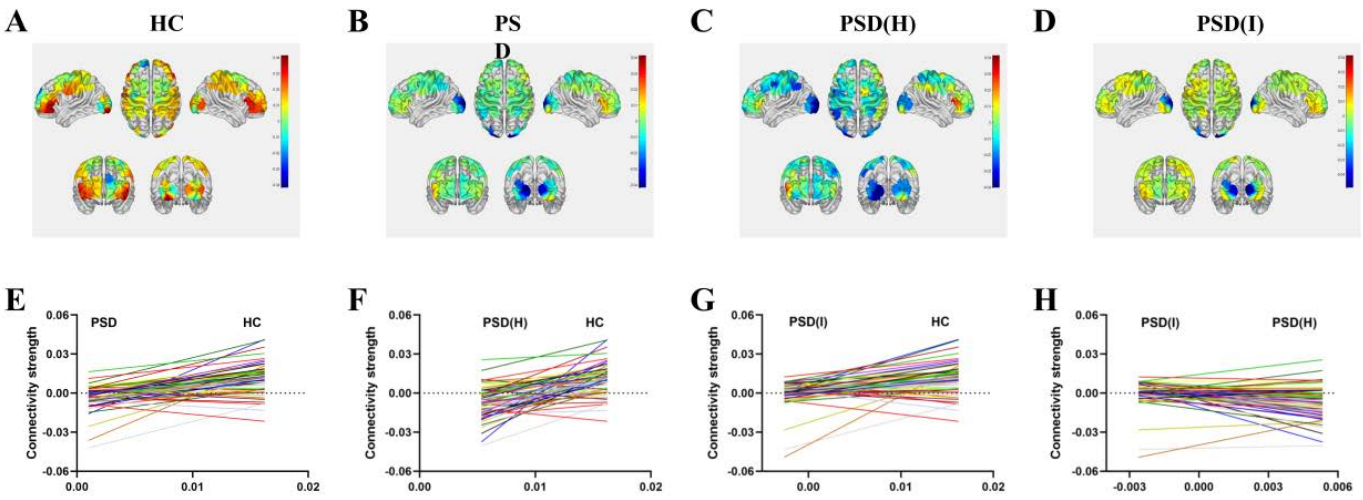

Figure 5. *Activation features of brain regions and general linear model (A-H). HC group: Healthy control group; PSD group: Post Stroke Dysphagia group; PSD(H): PSD Hemorrhagic group; PSD(I): PSD Ischemic group. The figures (A-D) show the change of mean value. the larger the mean value, the closer the colour is to red, and the stronger the activation of brain region.*

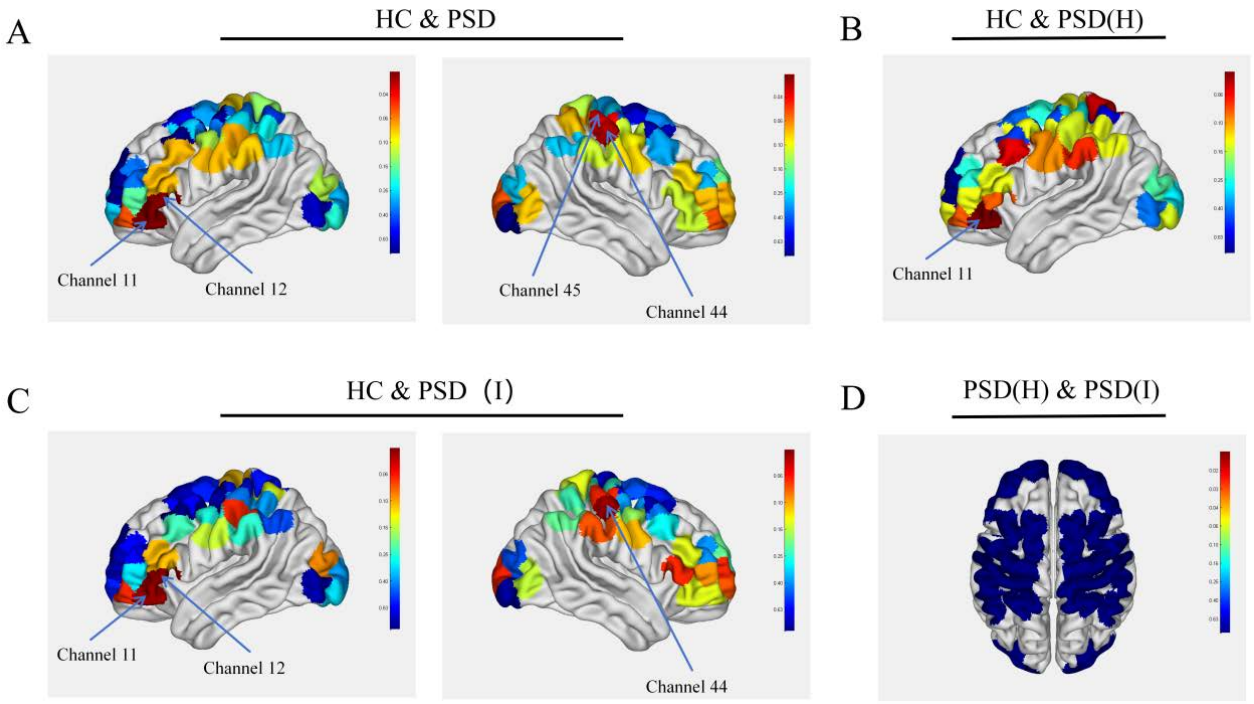

Figure 6. *Differences in brain region activation (A-D). HC group: Healthy control group. PSD group: Post Stroke Dysphagia group. PSD(H): PSD Hemorrhagic group. PSD(I): PSD Ischemic group. The figures (A-D) show the change of mean value. The larger the mean value, the closer the colour is to the mean value. The larger the mean value, the closer the colour is to red, and the stronger the activation of brain region.*

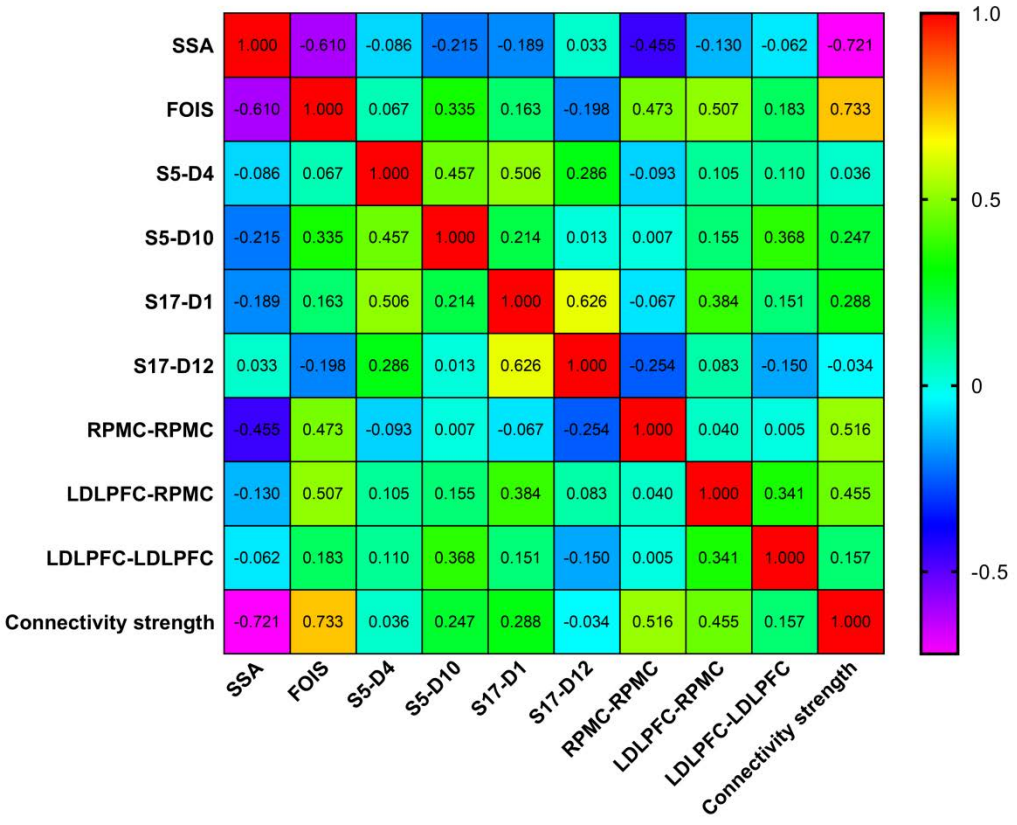

Figure 7. *Correlations heatmap with clinical characteristics. The figure shows the change of r value. The larger the r value, the closer the colour is to red.*

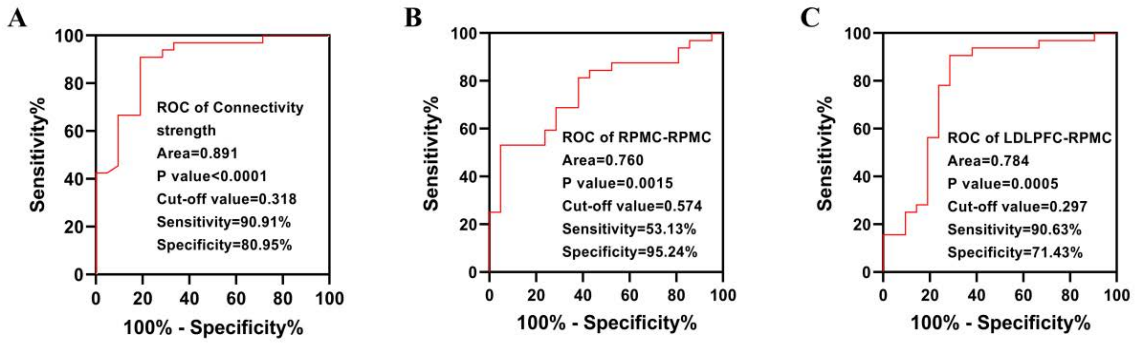

Figure 8. *Receiver operating characteristic curve. DLPFC: Left dorsolateral prefrontal cortex. RPMC: Right primary motor cortex.*

Table 1. *Cortical ROI corresponding to the channels and source detector.*

Cortical ROIs	Channels	S+D
RMC	30,32,44,45,46,47,49	S12,S17,S18,D1,D12,D14,D17,D19,D20
LMC	14,27,28,38,54,55,57	S6,S11,S14,S20,S21,D15,D21,D22
RSC	1,2,16,17,48	S1,S7,S18,D1,D12,D19
LSC	13,15,52,53,56	S6,S20,S21,D5,D11
RSMA	31,33,34,35,50,51	S12,S13,S19,D14,D17,D20
LSMA	29,36,37,39,40,41	S11,S14,S15,D15,D18,D23
RPFC	3,4,5,6,7,18,19,20,21,22	S2,S3,S8,S9,D2,D3,D7,D8
LPFC	8,9,10,11,12,23,24,25,26	S4,S5,S9,S10,D3,D4,D9,D10

ROI: Regions of Interest; S:Source; D:Detector; RMC: Right Motor Cortex; LMC: Left Motor Cortex; RSC: Right Sensory Cortex; LSC: Left Sensory Cortex. RMC: Right Motor Cortex; LMC: Left Motor Cortex; RSC: Right Sensory Cortex; LSC: Left Sensory Cortex; RSMA: Right Supplementary Motor Area; LSMA: Left Supplementary Motor Area; Right Prefrontal Cortex: RPFC; Left Prefrontal Cortex: LPFC

Table 2. *Demographic and clinical data (mean±SD).*

Variables	HC (n=26)	PSD (n=53)	*P*
Age (years)	60.15±8.399	63.08±10.33	0.214
Gender (Males:Females)	16:10	31;22	0.809
Stroke type (Hemorrhagic: Ischemic)	NA	29:24	NA
Lesion site(right:left)	NA	28;25	NA
SSA	NA	29.89±4.122	NA
FOIS	NA	3.170±1.438	NA
Variables	PSD(H) (n=24)	PSD(I) (n=29)	*P*
Age (years)	60.00±10.09	65.10±9.908	0.070
Gender (Males:Females)	14:10	17:12	0.787
Lesion site(right:left)	10:14	18:11	0.173
SSA	29.92±4.27	29.86±4.07	0.989
FOIS	3.13±1.36	3.21±1.52	0.839

HC Group: Healthy Control Group; PSD Group: Post Stroke Dysphagia Group; PSD(H): PSD Hemorrhagic Group; PSD(I): PSD Ischemic Group; SSA: Standardized Swallowing Assessment; FOIS: Functional Oral Intake Scale.

Table 3. *Channels with significant differences in connectivity strength.*

Channels	Cortical ROIs	FDR- corrected *p*			
		HC & PSD	HC & PSD(H)	HC & PSD(I)	PSD(H) & PSD(I)
11 (S5-D4)	LPFC	0.026	0.043	0.044	0.737
12 (S5-D10)	LPFC	0.026	0.083	0.041	0.670
44 (S17-D1)	RMC	0.031	0.052	0.044	0.737
45 (S17-D12)	RMC	0.040	0.052	0.068	0.737

ROI: Regions of Interest; S:Source; D:Detector; Left Prefrontal Cortex: LPFC; RMC: Right Motor Cortex; HC Group: Healthy Control Group; PSD Group: Post Stroke Dysphagia Group; PSD(H): PSD Hemorrhagic Group; PSD(I): PSD Ischemic Group; FDR: False Discovery Rate.

Table 4. *Significant correlation with the clinical characteristics.*

Connectivity strength/Channels/ROI	SSA r *p*	FOIS r *p*
Connectivity strength	-0.721 <0.001	0.733 <0.001
12 (S5-D10)	-0.215 0.123	0.335 0.014
RPMC-RPMC	-0.455 0.0006	0.473 0.0003
LDLPFC-RPMC	-0.130 0.352	0.507 0.0001

ROI: Regions of Interest; SSA: Standardized Swallowing Assessment; FOIS: Functional Oral Intake Scale; LDLPFC: Left Dorsolateral Prefrontal Cortex; RPMC: Right Primary Motor Cortex.

Correlations with clinical characteristics:

Correlation analysis with the clinical assessment indexes SSA and FOIS found that the average functional connectivity strength of the swallowing cortex in the PSD group had a negative correlation with SSA scores ($r=-0.721$, $p<0.001$) and a positive correlation with FOIS ratings ($r=0.733$, $p<0.001$). except for channel 12 (S5-D10) ($r= 0.335$, $p=0.014$), all the remaining channels were not correlated with any of the clinical assessment indicators. According to the distribution of fNIRS brain channels, we found that channels 11,12 were located in the left dorsolateral prefrontal cortex (LDLPFC) and channels 44,45 were located in the right primary motor cortex (RPMC), and we calculated the homologous and heterologous brain network connectivity of LDLPFC and RPMC. homologous and heterologous brain network connection strengths, and correlation with SSA and FOIS showed that RPMC-RPMC was negatively correlated with SSA ($r=-0.455$, $p<0.001$); RPMC-RPMC was positively correlated with FOIS ($r=0.473$, $p<0.001$); LDLPFC-RPMC was positively correlated with FOIS ($r=0.507$, $p<0.001$); LDLPFC-LDLPFC had no correlation with either SSA or FOIS (Figure 7; Table 4).

ROC curve analysis:

To further explore the critical value of the connectivity strength of the relevant brain networks reflecting the dependence of PSD patients on tube feeding (FOIS<grade 4), we plotted the ROC curves of the relationship between the FOIS-related brain networks and whether the PSD patients were dependent on tube feeding or not. As can be seen in Figure 7, when the average functional connectivity strength of the swallowing cortex brain network was ≥ 0.318, the functional connectivity strength of the homologous brain network RPMC-RPMC was ≥ 0.574, and the functional connectivity strength of the heterologous brain network LDLPFC-RMC was ≥ 0.297, the probability of PSD patients relying on tube-feeding to eat was lower, i.e., the probability of eating by mouth was higher ($p<0.0005$, see Figure 8A-C).

Discussion.

In this study, we explored the characteristics and differences of brain network functional connectivity and brain region activation in swallowing-related cortical task state in healthy adult subjects and PSD patients by fNIRS. Firstly, compared with the HC group, the PSD, PSD(H) and PSD(I) groups showed significantly lower strength of brain network functional connectivity and significantly decreased activation of specific brain region channels, suggesting that weakened brain network functional connectivity and insufficient activation of related brain regions may lead to the impaired swallowing function after stroke, and also that the brain regions with significantly decreased activation, the RMC and the LPFC, are the potential brain regions for brain function regulation in PSD patients; Secondly, correlation analyses were conducted to characterise and characterise differences in swallowing-related cortical task-state brain functional connectivity between healthy adult subjects, the activation level of channel 12 (S5-D10), the functional connectivity strength of homologous brain network RPMC-RPMC and heterologous brain network LDLPFC-RPMC in PSD patients correlated with SSA or FOIS. It is suggested that the degree of dysphagia in patients with PSD can be reflected by the intensity of functional connection of the brain network or the degree of activation of brain regions, LDLPFC and RPMC may be more accurate neuroregulatory targets for improving swallowing function in patients with PSD. Finally, ROC curve analysis shows that the average functional connection strength of the swallowing cortex and the critical value of functional connection intensity of homologous brain network RPMC-RPMC and heterologous brain network LDLPFC-RPMC can be used as potential clinical markers of whether PSD patients rely on tube feeding or not.

The biggest advantage of using fNIRS in this study is that it has faster time resolution, less artifact interference, and portability than fMRI technology, so it is more suitable for neuroscience research in natural situations such as daily life and work [15]. At the same time, there is a good correlation between fNIRS and fMRI task brain activation data [16,17]. At present, many studies have proved that fNIRS technology can effectively recognize the cortical activation pattern of the swallowing task state [18-20]. FNIRS can measure the changes in HbO_2 and HbR concentration on the cortical surface [20], while the change of HbO_2 concentration is the most sensitive index for the change of cerebral blood flow (CBF) [21], and has the strongest correlation with blood oxygenation dependent level (BOLD), and the signal-to-noise ratio is better than that of HbR [22]. Therefore, in this study, we use the changes in HbO_2 as an index to measure brain activity.

The mechanisms of PSD are complex, and the recovery of swallowing function requires the involvement of both motor and non-motor cortex. Several fMRI studies have shown that several brain regions, including primary somatosensory cortex, primary motor cortex, bilateral premotor and supplementary motor cortical areas, cingulate cortex, prefrontal, temporal, precuneus, subparietal lobule, cerebellum, and brainstem are associated with swallowing function [23-26], which provides a reference basis for the selection of RMC, LMC, RSC, LSC, RSMA, LSMA, RPFC and LPFC as ROI's. Previous studies reported primary motor cortex, bilateral premotor and supplementary

motor cortical areas as cortical centres for oral, pharyngeal and oesophageal muscles during active swallowing [16,23]; it is currently believed that primary motor cortex is involved in complex empirical movements, whereas bilateral premotor and supplementary motor cortical areas mostly process continuous movements [27]. Primary somatosensory cortices typically process general sensations applied to the face as well as gustatory stimuli to participate in the execution of swallowing movements [22]. The prefrontal cortex has been implicated in emotion, cognition and learning, and is capable of processing swallowing information and signalling to bilateral premotor and paramotor cortical areas, playing an important role in the pre-cognitive and oral phases [27,28]; at the same time, prefrontal cortical activity is modulated by flavour and gustatory stimuli, which change during swallowing [29]; the inferior frontal gyrus is able to participate in the control of non-verbal or orofacial sensorimotor behaviour, and several studies have demonstrated that fNIRS signal changes are strongest in the bilateral inferior frontal gyrus during the performance of swallowing tasks [30-33]. Our findings are in good agreement with those of fMRI [34-37]. When the above swallowing-related cortices (RMC, LMC, RSC, LSC, RSMA, LSMA, RPFC and LPFC) were selected as ROIs, differences in the strength and activation of brain network functional connectivity were observed between healthy subjects and patients with PSD, further confirming the importance of motor and non-motor cortices for normal swallowing function, which are collectively involved in swallowing and play a vital role in swallowing motor processing and integration plays a crucial role [38]. Meanwhile, it is suggested that the mechanism of PSD may be the weakening of functional connectivity of the brain network of the swallowing cortex and the insufficient activation of the related brain regions, which provides a reference for the rehabilitation treatment plan of PSD patients with multi-brain region intervention.

Analysis of channel differences in brain area activation showed that PSD patients had lower activation in swallowing brain areas than healthy subjects during the swallowing task, and significantly lower activation in specific channels (11, 12, 44, and 45) than the HC group, with channels 11 and 12 located in the LPFC, and channels 44 and 45 located in the RMC. Previous studies have found that the prefrontal cortex is closely related to cognitive behaviour, and is involved in the swallowing cognitive, preparatory and planning phases of swallowing [28], and frontal lobe lesions are closely related to oral phase disorders [39,40]. While the results of the present study suggested that the prefrontal cortex in the left hemisphere had a higher correlation with swallowing function than that in the right hemisphere. In addition, the motor cortex, as a relevant centre for swallowing function, is mainly involved in complex empirical actions [38], a the results of the present study suggested that the motor cortex in the right hemisphere had a higher correlation with swallowing function than that in the left hemisphere. correlation is higher than the left hemisphere. In summary, LPFC and RMC may be the key brain regions for impaired swallowing function in PSD patients and are expected to be potential targets for neuromodulation therapy. Meanwhile, our results also suggest that the activation of the swallowing cortical brain regions in the left and right brains is different during the performance of swallowing tasks in PSD patients. It is now generally accepted that the functional areas of the cerebral cortex for swallowing have significant interhemispheric asymmetry [41]. Unilateral hemispheric injury causes dysphagia mainly due to the presence of a "dominant" hemisphere in swallowing behaviour, but the pattern of brain lateralisation of swallowing function is uncertain. The present study provides a reference for the study of brain lateralisation of swallowing function.

In order to explore the correlation between brain network functional connectivity strength and clinical assessment indexes, we correlated the average brain network functional connectivity strength of swallowing-related cortex, homologous and heterologous brain network functional connectivity strengths between LDLPFC and RPMC with SSA and FOIS, respectively, and the results showed that the average brain network functional connectivity strength of swallowing-related cortex correlated negatively with SSA and positively with FOIS. The results showed that the average brain functional connectivity strength of swallowing-related cortex was negatively correlated with SSA and positively correlated with FOIS, suggesting that the higher the brain functional connectivity strength was the lower the degree of swallowing disorder. Meanwhile, RPMC-RPMC was negatively correlated with SSA; RPMC-RPMC, LDLPFC-RPMC were positively correlated with FOIS, further suggesting that the higher the activation of the brain regions of LDLPFC and RPMC, and the better the functional connectivity of the brain network, the lower the degree of swallowing dysfunction of PSD patients, which is basically in line with previous studies [42,43]. More importantly, the results of the present study further narrowed down the range of brain regions with higher correlation with swallowing dysfunction, suggesting that LDLPFC and RPMC may be more precise targets for neuromodulation.

To further explore the critical value of the connectivity strength of the relevant brain networks reflecting the dependence of PSD patients on tube feeding (FOIS < grade 4), we plotted the ROC curves of the relationship between the FOIS-related brain networks and whether the PSD patients were dependent on tube feeding or not. The results showed that the probability of PSD patients not relying on tube-feeding for feeding was greater when the average swallowing cortical brain network functional connectivity strength in the swallowing task state was ≥0.318, when the homologous brain network RPMC-RPMC connectivity strength was ≥0.574, and when the heterologous brain network LDLPFC-RPMC connectivity strength was ≥0.297, suggesting that the average brain network functional connectivity strength and LDLPFC, RPMC could be used as potential clinical markers of whether PSD patients are dependent on tube feeding.

It should be noted that the clinical manifestations, treatments and prognoses of different types of stroke vary greatly, and at present, clinical symptoms and imaging findings are still used as the main basis for their identification of cerebral haemorrhage and cerebral infarction [44], and there is a lack of functional imaging studies for assessing the differences in brain function between the two. Therefore, it is of great significance to find methods and assessment indexes for assessing brain function

in different types of stroke, which is important for personalised treatment and improving the prognosis of patients with different types of stroke. In view of this, in this study, PSD patients were analysed in the subgroups of hemorrhagic and ischemic, and it was found that the HC group was significantly higher than the PSD(H) group and the PSD(I) group in the strength of the brain network functional connectivity and the degree of activation of the brain regions, while the PSD(H) group was lower than the PSD(I) group in the strength of the brain network functional connectivity and the degree of activation of the brain regions, but the difference was not statistically significant. The results of this study suggest that there may not be a difference between PSD(H) and PSD(I) patients in swallowing-related cortical brain function, but fNIRS can only capture the blood oxygenation signals in the cortex of the brain, and cannot detect the signals in the deeper parts of the brain (e.g., the insula, cerebellum, and brainstem, which are closely related to swallowing) [45], so it is necessary to further investigate the differences in the future in combination with fMRI.

Limitations.

The present study provides new insights in exploring brain functional connectivity and brain region activation in PSD patients, but there are some limitations.

Firstly, the spatial resolution of the fNIRS technique limits the assessment of the role of deep brain structures (e.g., insula, basal ganglia, cerebellum, and brainstem) in swallowing activity. These regions play an important role in the swallowing process, and failure to include them may have compromised the depth of a comprehensive understanding of swallowing function. Future studies may consider incorporating the use of techniques such as fMRI to obtain a more comprehensive picture of functional brain activity.

Secondly, some patients with severe dysphagia are unable to perform actual swallowing manoeuvres and can only participate in the study by imagining swallowing. This alternative task may not fully simulate the real swallowing process, thus affecting the accuracy of functional brain activation. Therefore, future studies need to develop more accurate swallowing task paradigms to reduce the impact of this discrepancy on study results. Further, although the present study observed a possible difference in the level of left and right brain activation during the swallowing task in patients with PSD, no detailed subgroup analyses of the left and right hemispheres were performed. Future studies should explore this phenomenon of lateralisation to gain a deeper understanding of brain asymmetry in swallowing control.

Finally, the fNIRS headcap probe distribution used in this study failed to fully cover the temporal lobe region, which may have affected the accurate assessment of temporal lobe activation during swallowing movements. In future studies, we will use more advanced spectral headcaps to ensure that the temporal lobe region is fully covered to more accurately explore its activation and mechanisms involved in swallowing movements.

Conclusion.

In this study, functional near infrared spectroscopy (fNIRS) was used to reveal significant abnormalities in brain network functional connectivity and brain region activation in swallowing-related cortex in patients with post-stroke dysphagia (PSD). Compared to healthy controls, PSD patients exhibited diminished strength of brain network functional connectivity and abnormal brain region activation patterns. The findings suggest that the strength of brain network functional connectivity in LDLPFC and RPMC is closely related to the severity of swallowing function, and that these two brain regions may be potential neuromodulatory targets for PSD treatment. In addition, this study found that the critical value of the functional connectivity strength of the brain network of the swallowing cortex may serve as a clinical marker for assessing whether patients with PSD are dependent on tube-feeding for food.

Data Availability Statement.

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflict of interest.

The authors report no conflict of interest. I confirm that there is no conflict of interest with all the co-authors.

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Author Contributions.

The work described here was done in mutual assistance with all the authors. Bangqiang Hou completed the data collection, performed statistical analysis, and drafted the manuscript. Yinxu Wang, Qing Wu and Ke Pan contributed to the research design and reviewed and edited the manuscript. Yaoming Luo and Yiya Wang collected references and revised the manuscript. Yutong Han, Yulei Xie and Jingjing Liu conducted data collection. All the authors read and approved the final version of the manuscript.

Ethic statement.

The study was approved by the medical ethics committee of the affiliated hospital of north Sichuan medical college. Ethical approval number: 2024ER9-1. And informed consent was obtained from all enrolled patients. This study complies with the Declaration of Helsinki. It was registered with the Chinese Clinical Trials Registry. Registration number: ChiCTR2400083503.

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