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Systematic review

Analysis of teleradiology tools in diagnostics, treatment of neurological diseases and review of the usage of mobile stroke units – a systematic review

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Abstract

Background: The increasing prevalence of neurological disorders necessitates the exploration of new technological solutions to enhance healthcare. This study aims to examine the impact of the Mobile Stroke Unit on therapy duration and assess the influence of teleradiology on the treatment and diagnosis of neurological diseases.
Material and methods: To gather articles for this review, we searched medical databases and employed MeSH terms in Feb. 2020. We employed the Rayyan system, a tool dedicated to conducting author-independent systematic reviews. We included articles that met the following criteria: English abstract related to teleradiology and neurology in human subjects. Ultimately, 41 articles were included (2 case reports, 15 case series, 2 comparative studies, 14 evaluation studies, 4 multicentre studies, 3 randomised studies, and 3 observational studies). We analysed the time from alarm to CT and from alarm to the therapeutic decision in 12 articles focused on the Mobile Stroke Unit.
Results: A reduction in both times was observed compared to traditional treatment. Most articles in our review examined the telestroke system. Additionally, the use of telemedical tools was found to contribute to positive long-term prognosis in therapeutic processes.
Conclusion: The main conclusion of this study is that the increase in funding the newest teleradiology tools seems sensible. Moreover, it can unburden the health care system and reduce costs.

Keywords: teleradiology; neurology; stroke; telemedicine; diagnostic imaging; computer tomography.

1. Introduction

Teleradiology is a branch of radiology that allows remote transmission and review of diagnostic radiological images to examine patients when the radiologist is not present at the unit. Historically teleradiology was developed when the demand for descriptions of new and urgent radiological examinations increased [1]. There is no doubt about the benefits of this solution, especially when a radiologist is not physically available in the medical facility [2]. The European Radiological Society, together with the American College of Radiology (ACR), have published white papers on teleradiology practices, identifying advantages and disadvantages, and identifying best practices [3, 4, 5]. ACR indicates that equipment used in teleradiology must be approved by the Food and Drug Administration (FDA).

Globally ageing society causes the increase of frequency of neurological disorders [6]. Acute ischaemic stroke (AIS) is the fourth most common cause of mortality in the United States (USA) and the leading cause of disability. The limited access to the specialists of neurology in plenty of countries is a worldwide phenomenon. Medical doctors often find employment in metropolitan clinical hospitals, which leads to the aforementioned lack of access to such high-qualified medical care for the people living out-of-town [7]. Research showed that in India equivalent neurological disorders among countryside-living patients with limited access to the high-qualified multi-specialized medical centres reached higher level mortality caused by a stroke and that between 6 and 8 million people are ill with epilepsy [8]. It seems the further development of telemedicine will have a crucial impact on reducing morbidity in the era of deficit of specialists in this domain. The particular branch of telemedicine is teleradiology because it finds usage in many fields of medicine. It is used successfully in orthopaedics [9]. Paryavi et al. in their research demonstrated the diagnoses of children's traumas in a cubital joint were based on the telemedical system, these being made via analysing sent images taken by the iPhone, and these were equally reliable compared to those being made in a standard way. The surgeons use the achievements of teleradiology very willingly as well [10]. The team of Japanese and German scientists and surgeons was able to use a telemedical system for mid operational visualisation without the necessity of leaving the operating theatre or a need for external help in reference to imaging data. Steerage via imaging data with sterile gloves and the touchable screen was much more comfortable, more accurate and faster beside the other modalities [11].

There is no doubt that as every resilient-progressing domain of science, teleradiology needs continuous improvement to eliminate the mistakes [12]. The main aim of this research is to verify the importance of teleradiology in the diagnostic process of neurological diseases and explore its impact on healing processes and to explore which teleradiology service is being used most commonly nowadays.

2. Materials and Methods

Towards the accurate examination of the presented issue, in this paper, we held a systematic review of scientific literature on teleradiology and neurology in Feb. 2020. To this review, we qualified publications that fulfilled these conditions: the article has to be about teleradiology and neurology, it has an abstract, it is related to humans, the article has to be published after 2000.01.01 and has to be free of charge. We excluded from review articles that didn't meet the above conditions, weren't written in English, duplicates and were inadequate for this research (Supplement 1). The process of collecting, including and excluding data, was summarised into the flow diagram (Figure 1).

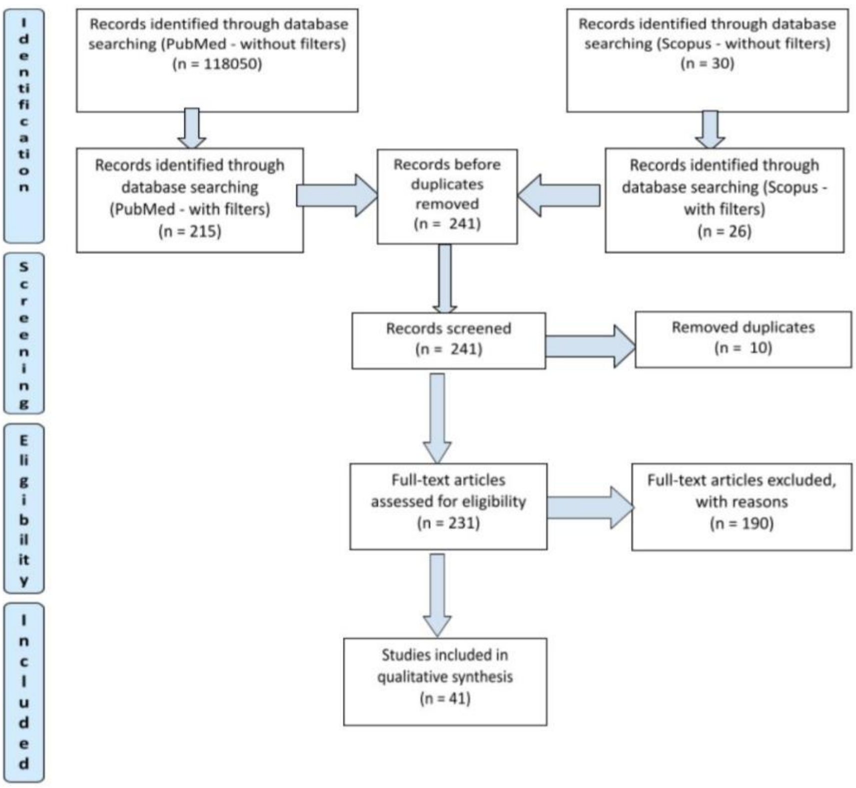

Figure 1. Flow diagram

2.1. **Sources of information and searching process**

Assortment and search of scientific papers to this review were conducted correspondingly with PRISMA guidelines [13]. Due to common access, we decided to use PubMed and Scopus platforms. To avoid mutual impact on each other's decisions which article includes or excludes, every author of this paper chose them independently. We also decided to use Rayyan Qatar Computing Research Institute (QCRI) [14], an intuitive tool dedicated to creating scientific reviews. The scope includes publications collected from Jan. 2000 to Jan. 2020. The following comprehensive combinations of MeSH entries that cover the subject of teleradiology and neurology were used to search for articles on PubMed: (Supplement 2), while on Scopus we used the terms "teleradiology AND neurology".

2.2. **Process of gathering and selecting data**

The first search in the PubMed database using the MeSH terms resulted in 118050 results. In the Scopus database, we have obtained 30 results. Then, we used filters like people only, time limits, full text or abstract. As a result, 215 results were obtained from PubMed. On Scopus 4 articles were excluded due to the lack of abstracts. After extracting articles to the Rayyan QCRI website, 10 duplicates were removed, and 231 articles were received. Then, an analysis was performed, based on which 190 articles were excluded, resulting in 41 articles being qualified for this systematic review. Each of them was analysed in terms of usefulness in the study. It was found that all articles met the criteria. Then we read whole articles and put the most significant data to the tables. All of the 190 excluded publications (Supplement 1) did not meet the assumptions of the study (e.g. lack of data in the article for analysis, work not related to the purpose of the review, paid access).

2.3. **Risk of bias assessment**

All articles were assessed for risk of bias according to the Cochrane Handbook guidelines for randomized and non-randomized controlled trials [71] by two independent reviewers. All discrepancies were resolved by consensus. The Cochrane risk assessment tool for bias includes the evaluation of selection bias, performance bias, detection bias, attrition bias, and reporting bias for randomized controlled trials. These were assessed using the options 'low risk,' 'high risk,' 'unclear risk' and 'not applicable'.

3. **Results**

All qualified publications are contained in table (Supplement 3). They were divided into separate types of articles: case reports, case series, comparative studies, evaluation studies, multicentre studies, randomised studies, observational studies.

3.1. **Case studies**

The only case study included in this review is related to a 74 years old woman with a head injury. After CT performed by MSU (Mobile Stroke Unit), doctors eliminated the probability of hemorrhagic stroke and skull fracture [15].

3.2. **Case series**

Spokoyny et al. in their aggregate analyse of compliance of radiological contraindications between vascular radiologist and Spoke Radiologist (thrombolysis in 261 cases) call it wonderful (95,4%, κ = 0,74, 95% CI 0,59–0,88) [16]. Puetz et al. in their research showed that doctors misdiagnosed patients via the Stroke Eastern Saxony Network (SOS-NET). Of 582 patients, complete imaging data were available for 536 patients (351 cerebral ischemic events, 105 primary intracranial haemorrhages, and 80 stroke mimics). The neuroradiologists detected discrepant CT findings in 43 patients (8.0%) that were rated as clinically relevant in 9 patients (1.7%). The interobserver agreement on ASPECTS between stroke neurologists and expert readers was substantial (κ (w) = 0.62; 95% confidence interval 0.54-0.71) [17]. Zerna et al. also indicated variances between radiological experts and neurologists in diagnosing 97 of 432 patients (22,5%), with underestimation (n = 48, 11,1%) and overestimation (n = 49, 11,3%) EIC grade [18].

Hov et al. described the usage of MSU in remote diagnosis of subarachnoid haemorrhage in Norwegian cottages spaced about 45-160 km from the neurosurgical ward. He emphasised the fact of saving 2-2,5h on diagnosis and neurosurgical intervention [19]. Grunwald et al. indicated significant shortening time which lasted from first symptoms to CT scan (93 min, IQR 62-181 min). It was based on 15 case studies, and this lasted from first symptoms to thrombectomy (median=85 min) [20].

Kostopoulos et al. indicated the choice made by a prehospital diagnosing process with MSU as an asset [21].

3.3. **Assessment of the impact of using MSU on diagnosis and treatment**

MSTU (Mobile Stroke Treatment Unit) is an advanced medical unit in the form of a specialized ambulance equipped with a portable CT scanner and tools enabling immediate diagnosis and treatment of stroke [43]. MSTU operates on-site, allowing for initial diagnostic tests, such as CT scanning, administering of contrast medium and other appropriate medications before the patient is transported to the hospital [43]. Teleradiology (image transmission) and telemedicine (real-time video conferencing) are integral parts of the MSU concept [44]. In order to use the potential of MSU most effectively, these units must be available to suspected stroke patients. For this reason, an appropriate stroke questionnaire is needed, which will probably confirm or exclude the existence of a stroke. As shown (Supplement 4), the MSU may reduce the time it takes to help below the "golden hour". This term comes from the surgeon R. Adams Cowley, who noticed that the earlier the patient receives help - especially within the first hour of injury - the higher are chances for the patient to survive. The PHANTOM-S study confirmed this conclusion [45], as well as the MSU Houston program, which showed a reduction in the time it took to help stroke patients [46]. Such short times from the alarm to the decision on the implemented treatment may contribute to better clinical results, but they are not known due to the small number of patients participating in the studies. Some studies, however, show the relationship between positive results of patients who received help in the appropriate time frame [47, 48]. The control group for these comparisons typically consisted of patients treated in standard emergency settings, without access to mobile CT scanning or remote neurologist consultations, highlighting the contrast in treatment outcomes between MSU-based and conventional care.

3.4. **Comparative study**

Taqui et al. in their comparative study compared a group of 100 patients treated with MSU to these treated in ED (emergency department). There was a significant reduction of median alarm-to-CT scan completion times (33 minutes MSTU (mobile stroke treatment unit) vs. 56 minutes controls, $p < 0.0001$), median alarm-to-thrombolysis times (55.5 minutes MSTU vs 94 minutes controls, $p < 0.0001$), median door-to-thrombolysis times (31.5 minutes MSTU vs 58 minutes controls, $p = 0.0012$), and symptom-onset-to-thrombolysis times (97 minutes MSTU vs 122.5 minutes controls, $p = 0.0485$) [22]. Fong et al. proved thrombolysis guided via telemedicine in comparison to the traditional one gives similar results. In total, 152 patients were treated with IV thrombolysis; 102 patients were treated with neurologist on-site; whereas 50 patients were treated by internists with telestroke. Fifty-two percent of the telemedical group achieved excellent outcomes compared to 43% of the neurologist on-site group ($P = 0.30$). Symptomatic intracranial hemorrhage rate (4.0% versus 4.9%, $P = 1.0$) and mortality (8.3% versus 11.9%, $P = 0.49$) were comparable [23]. Mikulik et al. proved that time and quality of Transcranial Doppler (TCD) and carotid duplex (CD) examinations made in-person by specialists compared to examinations conducted by inexperienced medical care worker via telemedicine were similar. Respectively medians of time which lasted examination in person and via telemedicine totalled 15 (range from 10 to 35) vs. 30 (15 to 50) for CD ($P = 0,07$) and 18 (15 to 30) vs. 45 (30 to 55) for TCD ($P = 0,002$) [24].

3.5. **Evaluation study**

Mainali et al. proved that training of nurses and simultaneous acting in telestroke system shortened time from diagnosis to treatment (38,9 minutes in comparison to 24,4 minutes via using telestroke; $P <0,04$) [25]. Wu et al. declared that compliance of making a diagnosis for 174 patients via telemedicine and via ordinary neurological examination intramurally totalled 88% ($\kappa = 0,73$) [26]. Alotaibi et al. created a mobile application that connected every single stroke team member. Due to this, they shortened time from diagnosis to treatment significantly (median of time before using an app=127 minute; after using an app=69 minute; $P <0,001$) [27]. Shkirkova et al. reported the time-shortening of 'from door to needle" period (51 min, interquartile extent 40,5-69,5) below a domestic guideline of demeanour in case of stroke in the result of using the system which integrated whole stroke team [28]. Demeestere et al. reported increased access to thrombolytic treatment in the countryside in Australia via using telestroke [29]. Rubin et al. described the lossless transmission of USG scanning TCD and CD [30]. Nguyen-Huynh et al. also reported a shortening of "from door to needle" period's lasting (19,5min, $P <0,001$) [31]. Kettner et al. reported beneficial usage of CTA in MSU what caused a more accurate choice of target hospital [32]. Whetten et al. proved that usage of ACCESS decreased neuro-emergent stroke patient transfers from rural hospitals to urban settings from 85% to 5% (no tPA) and 90% to 23% (tPA), while stroke specialist reading of patient CT/MRI imaging within 3 h of onset of stroke symptoms increased from 2% to 22%. Results indicate that the use of ACCESS (Access to Critical Cerebral Emergency Support Services) has the economic potential. It is possible to save \$4,241 (\$3,952-\$4,438) per patient and increase QALYs by 0.20 (0.14-0.22). This increase in QALYs equates to ∼73 more days of life at full health [33]. Phabphal et al. developed and researched the effectiveness of cheap systems devoted to making teleconsultations. The analysis of each 100 images took 48s and cost 400 Thai bahts. The research showed that it's possible to achieve good quality using this system in diagnosing strokes [34]. Osborne et al. devised a segregation system in order to make CT interpretations faster. The average time of reading CT images of acute stroke lasted 6,5 min. It meant 17,3 min improvement in ratio to the next priority CT in their practice (range of confidence 17,2-17,4 min, P <0,001). The amount of analysed CT totalled 350,495 [35].

3.6. **Multicenter and randomised study**

Walter et al. in a randomised study of 100 patients (53 in the pre-hospital group treated for stroke, 47 in the control group) showed a reduction in the time from alarm to treatment decision to 35 min (IQR 31–39) compared to 76 min (63–94), (p <0.0001); median difference 41 min (95% CI 36–48 min) [37]. Ebinger et al. report shortening the time from diagnosis to thrombolysis by 15 minutes (95% CI, 11–19) [38]. Nyberg et al. also report shortening times from alarm to CT and from alarm to the decision. The average time to send MSU to receive images in the teleradiological system was 21 minutes and 44 minutes in MSU and control groups, respectively (P <0.001). The average time to send a radiological report was 34 minutes and 54 minutes, respectively (P <0.001) [39].

3.7. **Observational study**

Itrat et. al showed that the times from door to completion of CT (13 minutes [IQR, 9-21 minutes]) and from door to intravenous thrombolysis (32 minutes [IQR, 24-47 minutes]) were significantly shorter in the MSTU group compared to the group control (18 minutes [IQR, 12-26 minutes] and 58 minutes [IQR, 53-68 minutes] respectively). Times for CT interpretation did not differ significantly between groups [40].

Russel Cerejo et al. in their study involving 155 patients, they noted a significant reduction in time, including median door to initial CT (12 minutes vs 32 minutes), CT to IAT (82 minutes vs 165 minutes), and door to MSTU/primary stroke depart brain (37 minutes vs 106 minutes) among the two groups. In comparison with 6 patients who reported directly to our facility, the MSTU times were also shorter [41].

Kunz et al. compared the results of pre-hospital thrombolysis in the mobile stroke treatment unit (STEMO) - a group of 427 patients with the group of 505 patients treated with conventional care. Among the patients in the STEMO group, 305 STEMO and 353 patients in the conventional care group were included in the study because only they met the inclusion criteria. 161 (53%) patients in the STEMO group compared to 166 (47%) in the conventionally treated group had a Rankin score (mRS) of 1 or less (p = 0.14). Compared with conventional care, the adjusted odds ratio (OR) for STEMO care for the original result (OR 1.40, 95% CI 1.00–1.97; p = 0.052) were not significant. Intracranial haemorrhage (p = 0.27) and mortality within 7 days (p = 0.23) did not differ significantly between treatment groups [42].

4. Discussion

4.1. **Main findings**

The main purpose of this study was to review the available literature and determine how the use of teleradiology affects the diagnostic and therapeutic processes of neurological patients. It was also checked what technical solutions were implemented in particular scientific publications. In our review, we included 41 articles, among which 14 were evaluation studies, 15 series of cases, 4 multicentre studies, 3 randomised studies, 3 observational studies, 2 comparative studies and 2 case reports. Most scientific articles have reported the positive impact of teleradiology use in the treatment and diagnosis of strokes, including the use of MSU. The least of them concerned about the use of ultrasound in neurology. We also extracted 12 articles to evaluate the time from alarm to CT in MSU and the time from alarm to the therapeutic decision. We noticed that in most of the cases, the use of MSU shortened the time to make a decision and shortened the diagnostic process. The sum of all persons that took part in all included studies is 373,622.

4.2. **Comparison with existing literature**

We didn't include systematic reviews to our paper, and papers which were focused on one, particular issue or did not check the use of different solutions. 3 reviews tracked about MSU and reported positive aspects of using mobile CT scanning, prehospital thrombolysis, mostly emphasising reduction of treating time [6, 10, 11]. One of the reviews tracked about sending transcranial US images in diagnosing and treating stroke patients. The rest of the reviews evaluated the usage of telestroke systems [7, 9, 14, 49, 50] exclusively. Mrak et al. in their research (excluded from our review) reported about the usage of the teleradiological connecting system in neurosurgery [51]. Huffer et al. reported a high 83% compliance of remote usage of echocardiography in comparison to the stationary one (excluded from the review because it was not related to neurology) [52].

4.3. Comment on the results

We noticed plenty of positive results of usage of teleradiology in the diagnostic and treating process. Authors reported fast intervention in case of stroke. They noticed positive economic aspects and long-term improvement of patients' prognoses. Moreover, they suggested that prehospital diagnostics enable redirecting the patient to the right medical centre, which treating potential is the most accurate to the clinical stage. Doctors find MSU usable in stroke diagnostics and also in different cases like faints, posttraumatic exclusion of brain's injuries.

A detailed analysis of the reviewed studies revealed that the frequency of incorrect or delayed diagnoses in traditional emergency settings resulted in inappropriate treatment in up to 12% of cases. These errors often occurred due to a misdiagnosis of stroke mimics, such as migraines or seizures, or an inability to promptly identify hemorrhagic versus ischemic strokes. In contrast, MSUs, equipped with mobile CT scanners and teleradiology systems, were able to reduce the occurrence of such errors to less than 5%. The presence of remote neurologists who could review images in real-time also played a key role in improving diagnostic accuracy.

The small differences between stationary and teleradiological interpretations of CT scans exist, but the proportion isn't huge. It's proved that making TCD and CD don't need the presence of neurologists. This process can be remote by keeping a satisfactory result. The MSU equipment enables teleconsultations between the ambulance team and radiologists. In the era of lack of medical staff, these tools seem useful. We noticed the significant time reduction from alarm to CT and from alarm therapeutic decisions. Making access to thrombolytic treatment more available in the countryside was noticed by the researchers as well. In most studies reviewed, the control group consisted of patients receiving care in traditional emergency departments without the use of Mobile Stroke Units or teleradiology systems.

4.4. Review restrictions

Due to the variety of research which covered aspects raised by us in this article, it was not possible to conduct a meta-analysis. During work on our quantitative review, lots of articles were excluded for the reason of not fulfilling the main criterion - treating about neurology. In our opinion, the strong side of our research is adherence to the guidelines of PRISMA.

4.5. Conclusions

Teleradiological solutions come ahead of the needs of an increasing number of neurological patients (including patients with stroke). There is no doubt that teleradiology is a future of neurology and the future of whole medicine. The health systems which struggle with financial problems could be unburdened via teleradiology. The quality/cost ratio will improve. The development of telestroke systems and proper funding seems to be justified because it would enable the economization of treating strokes. It is necessary to carry out further research aimed at monitoring the development of this tool in medicine.

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