

# A Framework for Telestroke Network Design

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## 1. Introduction

Stroke is the third leading cause of death and leading cause of adult long-term disability in western industrialized countries. In stroke units providing special expertise, stroke patients receive highly efficacious care (Pollack et al., 2007). However, stroke units cannot be implemented in particular in sparsely populated rural areas because of a shortage of experienced neurologists (Audebert & Schwamm, 2009). As compensatory measures, telemedical solutions are increasingly applied within “telestroke” networks to provide neurological expertise from “hubs” to small primary care hospitals (“spokes”) (Audebert 2006; Müller et al., 2006). Due to various environmental factors and personal preferences, different types of telestroke networks have emerged especially in Europe and the United States within the last ten years (Schwamm et al., 2009a; Günzel et al., 2010).

In these networks, various pilot studies have demonstrated that valid decisions on thrombolytic therapy, the most important and time-critical therapy for the majority of acute stroke patients, and on a variety of further special interventions can be made accurately with the aid of telemedical expert support (Audebert et al., 2006; Audebert et al., 2009). Since telemedicine has proven to be a valid supplemental procedure in the treatment of acute stroke patients, primary care hospitals, especially in less populated regions, increasingly show interest in complementing their range of care by teleconsultations (Ickenstein et al., 2010). Those primary care hospitals may have totally different characteristics, some are e.g. small and located far away from the next certified stroke unit, while others are medium-sized and have neurology experts available on weekdays, but need support for night shifts and weekends. From a health economic point of view, these and many other different types of hospitals could benefit from telestroke care.

However, current telemedicine networks focus in their approaches mostly on one specific group of primary care hospitals, thereby excluding others and thus withholding specialized stroke care from a large number of stroke patients. The situation may even worsen when national reimbursement regulations for telestroke care within the DRG system will be introduced. Those regulations will most likely be tied to current practice of the dominant telestroke network design in the respective country, thereby raising an entry barrier for all other primary care hospitals.

To address these important issues for the first time, comparative health economic research into optimizing health care provision by both local stroke units and combinations of established telestroke network concepts is needed – and it must specifically take into account different regional environments. In this study, we first attempt to systematically characterize telestroke network structures and identify parameters describing different

established models. Second, we provide a novel structural framework and illustrate that fundamental but widely differing concepts do not compete with but rather complement each other from a primary care hospital point of view. Based on this framework, we suggest a proactive approach to customized network design.

This book chapter is organized as follows: in section 2 we give a brief overview of three leading telestroke network concepts. Section 3 presents a novel systematic taxonomy of telestroke network concepts based upon the central protagonist roles in telemedicine. Section 4 is devoted to presenting a hierarchical decision algorithm for choosing an optimal telestroke network design from the perspective of a primary care hospital. Finally, in section 5 we provide an exemplary case study of a fictitious hospital seeking to improve its stroke patient care by telemedicine.

## 2. International telestroke care

To identify the leading European and American telemedicine networks for acute stroke, a systematic literature review of the PubMed database (keywords “telemedicine” AND “stroke”, “telestroke”, “network”) and ensuing expert interviews were conducted in 2008 and again in 2010. Thirty-four networks in seven countries could be determined that were actively using telemedicine to enhance stroke care. A sample of these networks representing a conceptually wide range of telestroke applications were visited, and additional in-depth knowledge beyond journal publications was gleaned from interviews with network representatives (Günzel et al., 2010). Telestroke network structures were examined from medical and technological as well as health economic viewpoints.

In all telestroke networks the teleconsultant can view the patient’s brain scan (CT or MRI) that is uploaded onto a server platform via a DICOM interface. Furthermore, he is connected to the primary care hospital by a high-quality two-way video and audio transmission link and can observe the patient exam carried out bedside by the resident or attending physician. Having full control of the pan, tilt and zoom functions of the bedside camera, he can perform a thorough clinical assessment of the patient’s neurological status. On the basis of the information thus gathered, the stroke expert communicates his diagnosis and related therapeutic recommendations to the physician and finally provides a medical report sheet (Schwamm et al., 2009b; Theiss et al., 2009).

Driven by personal preferences, national funding opportunities, regional factors and different foci in stroke care, a wide range of different telestroke network concepts has emerged beyond the common denominator of providing basic anamnestic patient data, CT-scan and high-quality two-way audio and video transmission.

From a structural perspective, the leading active telestroke network approaches belong to three different fundamental types: (1) the drip-and-ship concept (e.g. Partners Telestroke Center in Boston, MA, USA), (2) commercial neurological teleconsultation provider (CTP, e.g. Specialists on Call Inc. in Leesburg, VA, USA) and (3) the telestroke ward concept (e.g. The Telemedical Pilot Project for Integrative Stroke Care in Munich, Germany). Those are described below in more detail.

### 2.1 TeleStroke: Drip-and-ship concept for emergency rooms

The world’s first telemedical stroke care network “Partners TeleStroke Center” started back in 2001 at the Massachusetts General Hospital (MGH) with two remote hospitals in Boston/USA (telestroke.massgeneral.org). Today, two academic stroke centers at MGH and

Brigham and Women's hospital provide about 200 acute stroke teleconsultations for 21 community hospitals in Massachusetts, New Hampshire and Maine per year. These primary care hospitals are mostly small community hospitals with CT-scan and laboratory available around the clock (Schwamm et al., 2004).

Implementing a "drip-and-ship" concept, the Partners TeleStroke Center network focuses on early identification of thrombolysis candidates in the network's primary care hospitals. Acute stroke patients admitted to a primary care hospital within the thrombolytic time window of 4.5 hours after symptom onset can be presented to the telestroke consultant, who discusses the findings with the on-site physician, and both together decide on a plan of care - in particular, the intravenous application of the clot-busting drug t-PA ("drip"). Up to 50% of the patients receiving t-PA, especially those developing complications, are transferred to one of the academic stroke centers ("ship"). Due to this narrow indication spectrum, all other acute neurological patients need to be treated or transferred by the primary care hospitals on their own.

It is the aim of the Partners TeleStroke Center network to promote the community hospitals to the status of an "acute stroke capable" hospital using the bridging concept within the first four hours of stroke. The neurological experts stress the relevance of the local network design and their personal educational relationship to the community hospital physicians, relying on the academic excellence of the university stroke centers (Farrell et al., 2008).

The total costs for both stroke centers and network hospitals are comparatively low, because Partners TeleStroke Center neurologists provide the teleconsultations as part of their in-house routine, and the community hospitals can request up to twelve consultations for an annual fee.

## **2.2 Specialists on Call: Commercial & global provider for teleneurological services**

The first commercial provider of acute neurological teleconsultations, Specialists on Call (SOC), was founded in 2003 by a renowned Harvard neurologist at the Massachusetts General Hospital. With 30 appropriately accredited and licensed neurological consultants spread all over the country, SOC currently serves the biggest network worldwide and offers around 1,000 consultations per month to 100 hospitals in twelve US states. SOC uses a globally distributed network structure of both primary care hospitals and neurological consultants without any regional hub-and-spoke relationship around a stroke center. SOC has followed this global, scalable approach to teleconsultation from its inception, and addresses a wide spectrum of customer hospitals with solutions tailored to their demands to most perfectly supplement the existing in-house expertise (McDonald, 2008). This includes different service options as e.g. 24/7, night-shifts only or at the weekends as well as relocation management for urgent patient transfer. While stroke patients constitute approx. 71% of all incoming requests, SOC in principle answers all inquiries about neurological patients.

In practice, a hospital affiliated with SOC contacts a call center managing the distribution of incoming requests to the neurological consultants and making sure that these have the necessary anamnestic, CT and hospital data available. The neurological consultant "on call" then calls back to the inquiring hospital and arranges the consultation from his telemedical workstation.

Hospitals contracting with SOC pay a fixed initial fee for provision and installation of the hardware, with monthly rates depending on hospital size, average stroke incidence and type, but independent of the actual number of teleconsultations. Alongside the medical support service, SOC maintains the provided equipment (McDonald, 2009).

### 2.3 TEMPiS: Regional stroke care network with telemedical stroke ward

Germany's most renowned telemedical network TEMPiS ([www.tempis.de](http://www.tempis.de)) was founded in 2002 as a pilot project publicly financed by the Bavarian State, the German Stroke Foundation and Bavarian health insurances. In 2006, TEMPiS managed the transition to regular health insurance financing based upon a special reimbursement contract. Today, two comprehensive stroke centers (Munich and Regensburg) provide about 3,500 neurological teleconsultations per year to 15 community hospitals in eastern Bavaria (Vatankhah et al., 2008).

TEMPiS systematically follows an integrative, regional approach to stroke care which is based on the idea of transferring the stroke unit concept to hospitals lacking neurological expertise. Basically, TEMPiS network community hospitals set up full-blown regional stroke unit "minus 24/7 neurologists", and the neurological expertise is provided by teleconsultations with the stroke units in Munich and Regensburg (Audebert, 2006).

There are several essential building blocks of the TEMPiS concept. First and foremost, network hospitals have to establish a separate "telestroke ward" to accommodate stroke patients, and must provide monitoring beds, laboratory and CT around the clock. They also need to have specially trained personnel for early rehabilitation (e.g. physiotherapy, speech and occupational therapy). The implementation of standard operating procedures for stroke patient care is the third pillar of the TEMPiS concept, and goes hand in hand with the introduction of dedicated quality management and a regular education and training program both for physicians and nurses. TEMPiS strongly emphasizes the personal relationship between stroke center experts, network hospital physicians and nurses (Müller et al., 2006).

Due to the high telestroke ward installation and running costs, TEMPiS focuses on medium-sized hospitals which treat at least 200-250 stroke patients per year. The total annual expenses for both stroke centers are refunded by the network hospitals, which in turn receive a lump sum in excess of the DRG reimbursement from the health insurances for every stroke patient.

## 3. Telestroke network concept taxonomy

Starting from our observations in operational telestroke networks, we attempted to derive a generic, systematic classification of teleneurological consultation approaches in acute stroke patient care. To this end, we first identified the different protagonists participating in this process. In principle, there are many players involved in telemedicine on a formal level – from health care providers, health insurances, accrediting agencies and legislative bodies up to governments –, and they can have quite different impact e.g. in the United States or Europe. On an operative level, however, obviously three different key protagonists can be clearly distinguished in a telemedical scenario: the patient, the local primary care hospital, and the expert neurological consultant. In an attempt to illustrate the range covered by individual telestroke network concepts, we associated each protagonist role with a single (semi-) quantitative parameter varying along a one-dimensional axis. Eventually, we indicated the fundamental network type with the highest and lowest level of each parameter at the respective end of its axis.

**The patient.** We first linked the *patient* role in telestroke networks to the parameter "clinical indication spectrum" measuring which patients are actually eligible for the neurological teleconsultation. Among the fundamental network concepts described above, the drip-and-

ship concept has the narrowest and most restricted clinical indication spectrum – it only provides neurological teleconsults for acute stroke patients eligible for thrombolysis or for neurosurgical or catheter intervention by referral to a tertiary care stroke center. On the other hand, commercially provided neurological teleconsults (CTP) are available to any patient in a hospital affiliated with the network, even way beyond the acute stroke condition. Therefore, the parameter axis “clinical indication spectrum” can be labeled as shown in Figure 1.



Fig. 1. The parameter “clinical indication spectrum” measures which patients are intended to benefit from neurological teleconsults.

**The primary care hospital.** In a second step, we associated the *primary care hospital* role with the parameter “required primary care hospital competency” measuring what amount of infrastructure and expertise is required for the hospital to receive the network’s teleconsultation service. Clearly, the telestroke ward concept as practiced by TEMPiS is the most demanding network – primary care hospitals have to arrange a full-blown stroke unit except for the 24/7 available neurologist, and they must have a minimum annual stroke incidence of about 200–250 patients. On the other hand, neurological teleconsults offered either within a drip-and-ship network or by a commercial provider are available to any affiliated hospital, irrespective of its stroke care infrastructure. In order to stress the contrast between the telestroke ward and drip-and-ship concepts, we labeled the “required primary care hospital competency” parameter axis as shown in Figure 2.

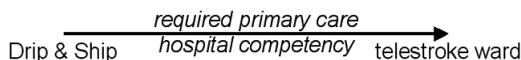


Fig. 2. The parameter “required primary care hospital competency” measures what conditions a hospital must fulfill to participate in a telestroke network.

**The expert consultant.** Finally, we characterized the *expert consultant* role by the parameter “consultant service spectrum” quantifying the degree of service offered by the teleconsult provider. Obviously, the regional TEMPiS telestroke ward concept ranks highest with respect to this parameter – it provides a wide range of educational and quality assurance measures beyond the actual teleconsult. In a drip-and-ship network, the tertiary care center still acts as referral hospital for stroke patients in need of neurointerventional procedures, while a non-locally distributed commercial teleconsultation network performs neither of these functions. Consequently, we labeled the “consultant service spectrum” axis as depicted in Figure 3.

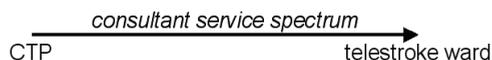


Fig. 3. The parameter “consultant service spectrum” measures which services the telestroke consultant provides.

**Available parameter space.** Having associated the three principal protagonist roles in telestroke networks with semi-quantitative parameters, it is natural to examine whether

these axes describe independent coordinates in an abstract three-dimensional space, i.e. if all combinations of values along these axes indeed correspond to valid network concepts, or if constraints restrict the practically available parameter configurations. We will clarify this issue by two examples.

(1) If e.g. in an exemplary telestroke network the consultant service spectrum provided is rather comprehensive, this is best attained with a high level of stroke competency and infrastructure on the part of the primary care hospital to go along with the educational service measures. Furthermore, this is practically feasible only for an intermediate number of patients. An extensive service including in person education (as opposed to videoconference teaching rounds) and quality assurance can only be provided in a regional network and not from a distance. For a rather narrow clinical indication spectrum like in a drip-and-ship network, the low incidence of teleconsults does not warrant this big personnel effort, while for a maximally wide indication spectrum offered by a commercial provider the lack of regional relationship prevents in person attendance.

(2) If on the other hand only a rather narrow clinical indication spectrum is admitted to teleconsults in a second, exemplary low-throughput telestroke network, no particularly high stroke competency can reasonably be required to be kept at hand in the primary care hospitals for only very few patients. Furthermore, such a low-throughput consultancy cannot provide a wide service spectrum, and it would not find acceptance, if it only offered mere teleconsults without at least some interhospital transfer management. This is in line with the procedures implemented in drip-and-ship networks.

**Triangular constraints.** These examples motivate that constraints exist between the three parameters, and suggest to join the axes together in a triangular shape such that in each corner the same labels come together. This process is schematically depicted in Figure 4 (left), and leads to a symbolic representation of viable network concepts as points inside the triangle. As Figure 4 (right) explains, each network concept is characterized by suitable parameter values on the three sides (edges) of the triangle. Consider e.g. the concept represented by the center of the triangle where the three dashed blue lines intersect: each dashed blue line runs perpendicular to one edge of the triangle and marks the degree of the parameter on the respective side very much like in a conventional x-y-coordinate system, but with oblique axes. The telestroke network concept exemplarily depicted in Figure 4 (right) corresponds to an equal mixture of the three fundamental telestroke network types.

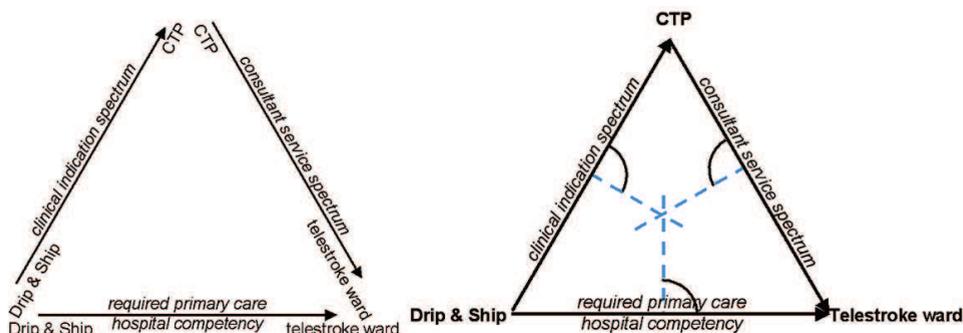


Fig. 4. Construction of the triangular classification scheme from the three individual parameter axes (left). For any valid telestroke network concept inside the triangle, the dashed blue lines indicate the respective associated parameter levels on the triangle's edges (right).

**Implications for viable network concepts.** Further conclusions can be drawn from this triangular parameterization of telestroke network concepts. First of all, the three fundamental telestroke network types are represented by the triangle's corners, and concepts similar to these types are placed close to the corners with similar parameter properties along both connecting edges. If a network similar to e.g. drip-and-ship is to be implemented, both "required primary care hospital competency" and "clinical indication spectrum" should be chosen "low".

Second, while for each viable network concept inside the triangle unique parameter properties can be read off along the edges (where the dashed blue lines end at right angles), the converse is not true: due to the constraints, we cannot choose all three parameter settings freely and end up with a workable network concept. This is exemplarily depicted in Figure 5: low required primary care hospital competency and wide clinical indication spectrum cannot be combined well with even a medium consultant service spectrum - it should be kept rather low.

There is not necessarily a single intersection of the three dashed blue lines starting at right angles from the desired parameter settings on the three edges of the triangle, since only any two of them can be chosen independently. The size of the small dashed blue triangle in the middle is a measure of the parameter settings' incompatibility: shifting the dashed blue lines appropriately indicates the necessary modifications of the initial "desired" settings that bring the intersection points closer together - and closer to a feasible solution.

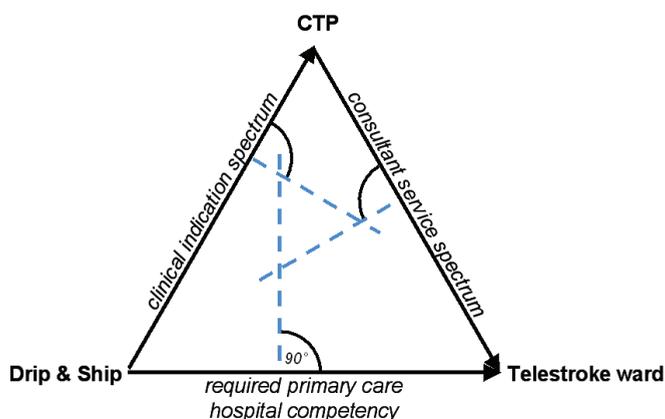


Fig. 5. Example of inconsistent "desired" parameter settings.

**Practical consequences.** How can a valid mixture of the three fundamental telestroke network concepts be implemented in practice, once it has been constructed according to the presented framework? A primary care hospital may choose a combination rather than any specific one of the fundamental types by associating with e.g. both a tertiary care center with neurointerventionalist specialties and a commercial teleconsultation provider. Specifically, only part of a telestroke ward could be implemented in the primary care hospital, patients eligible for neurosurgery could firstly be video-presented to a neurological consultant at a specialty center and then transferred to this clinic, and the remainder of stroke patients could be seen by a commercial teleconsultation service. **In this sense, the three concepts do not compete with but rather complement each other.**

#### 4. Choosing optimal telestroke network design

Having posited a generic classification scheme for telestroke network concepts in the previous section, we now want to address rather practical issues of optimal telestroke network design. By construction, the classification scheme covers the views of all three principal telestroke protagonists – patient, primary care hospital and expert consultant. While the patient has no obvious part in *designing* a telestroke network, this process can be viewed from both remaining perspectives – service provider and recipient.

The first pilot telestroke networks have been driven by the initiative of stroke expert centers providing neurological teleconsultation. However, today's status in telestroke is entirely different, as various types of regional telestroke networks coexist with global commercial providers of neurological teleconsults. In this situation, it is rather appropriate to assume the viewpoint of a primary care hospital seeking to improve their acute stroke patient care, than that of a stroke center searching for potential network hospitals. Such a primary care hospital will typically have a clinic for internal medicine currently taking care of acute stroke patients, but no in-house neurological expertise. In an attempt to structure the process of deciding about a suitable telestroke concept, we present a hierarchical decision algorithm specifying which questions to answer along the road to a functioning implementation of telestroke. In this decision algorithm, we include the parameter axes introduced in section 3. In the following paragraphs we describe and exemplify the major decisions to be taken, while the entire decision algorithm is depicted in Figure 6.

**Acute stroke incidence and regional stroke unit infrastructure.** The most important data to start from is the incidence of stroke patients in the primary care hospital under study and the availability and accessibility of regional tertiary care infrastructure: stroke units, neurosurgery, neuroradiology and vascular surgery. Both these factors affect the levels of the two parameters “clinical indication spectrum” and “service spectrum provided” introduced in section 3. Local stroke incidence alone is the main determinant indicating whether it is reasonable for a primary care hospital to arrange a stroke unit of its own according to the recommendations of national and international stroke guidelines. Under a cost-effectiveness point of view, a certified stroke unit is only warranted for an annual acute stroke incidence exceeding about 450 patients (German Stroke Association, 2008). This first decision is shown in the leftmost column of Figure 6.

**Preference: keep or transfer acute stroke patients?** If the stroke incidence in the primary care hospital does not warrant arranging a stroke unit of its own, the next strategic decision is whether the hospital wants to keep and treat stroke patients or rather transfer them. This decision is reflected in the level of the parameter “service spectrum provided” of the above telestroke classification scheme. In the case of a primary care hospital with more than about 200-250 acute stroke patients per year, it is questionable to transfer all these patients for two reasons. First, a substantial loss of revenue would be associated with losing these patients, and second, there has to be a referral stroke unit sufficiently close by having the capacity to accommodate them. So in the case of high stroke incidence it will probably be preferable to establish a telestroke ward in the primary care hospital and acquire neurological expertise by teleconsult. Which clinical and administrative measures must be implemented in a telestroke ward to generate additional revenue for the hospital is to a large degree determined by national reimbursement regulations within the DRG system. For low incidence or a general preference to transfer acute stroke patients the main question is whether there is a tertiary care referral center sufficiently nearby that is willing and able to receive the transferred patients. Such a referral center could also offer neurological

teleconsults to better select the cohort of patients benefiting most from a transfer. This step in the decision process is represented in the second column of Figure 6.

**Targeted stroke competency in own hospital.** In the next step, a primary care hospital preferring to keep acute stroke patients needs to specify the targeted degree of its own stroke competency. This corresponds to the parameter axis “required primary care hospital competency” introduced in the above classification scheme. In the case of high annual stroke incidence above 200-250 stroke patients it may well be reasonable for the primary care hospital to arrange a local telestroke ward of their own, including e.g. dysphagia diagnostics, early rehabilitation, speech and occupational therapy. Satisfying a set of conditions depending on national regulations, the hospital may become eligible for additional reimbursement for stroke patient treatment even without a local neurological department by acquiring teleneurological expertise. For low stroke incidence, it will probably be uneconomical to set up a whole telestroke ward, but patients will still benefit from some implemented measures and from neurological teleconsults - which along the way will also improve the hospital’s reputation. This part of the decision process is depicted in the middle column of Figure 6.

**Importance of regional relationship with the teleconsultant.** Subsequently, the primary care hospital has to state its preferences regarding a regional relationship with the teleconsultant. There can be several good reasons for such a regional, even personal, relationship, e.g. a long standing successful collaboration with a nearby stroke unit already serving as a referral hospital, or a personal acquaintance with a stroke neurologist. These aspects become increasingly significant, if the hospital prefers to transfer acute stroke patients. In this case, the primary care hospital should ask the intended referral center for additional teleconsultation service. This part of the decision process is depicted in the second column from the right in Figure 6.

**Economic viewpoint.** Finally, if there is no nearby stroke unit available for teleconsultation, or if the regional relationship is not relevant, the primary care hospital should look for commercial teleconsultation providers and compare their value for money. First, it should assess the clinical indication spectrum covered by the provider and its relevance for the hospital and patients. For every network type considered, primary care hospitals should calculate a price per patient presented to the teleconsultant. To that end, it needs to add the annual costs for every model - including the running costs (e.g. additional staff, rent for rooms), the amortization rates of the investment costs (e.g. for new equipment, search costs for new employees) as well as the monthly fees paid to the provider. This should be compared to the additional incomes resulting from reduction in patients’ length of stay, increase in the number of patients admitted to the hospital, additional reimbursement through the DRG system, which may vary significantly from system to system, and a better reputation. This part of the decision process is depicted in the bottom right section of Figure 6.

## 5. Exemplary case study

In order to round out the picture, we will consider an exemplary primary care hospital seeking the best way to improve stroke patient care by application of neurological teleconsultations. For the sake of the argument, we will work out our initial example sketched in section 4 and assume that the primary care hospital in question has a low-to-moderate annual incidence of 200 stroke patients, and the distance to the nearest stroke unit is slightly north of one hour by ambulance. Furthermore, suppose this nearest stroke unit is

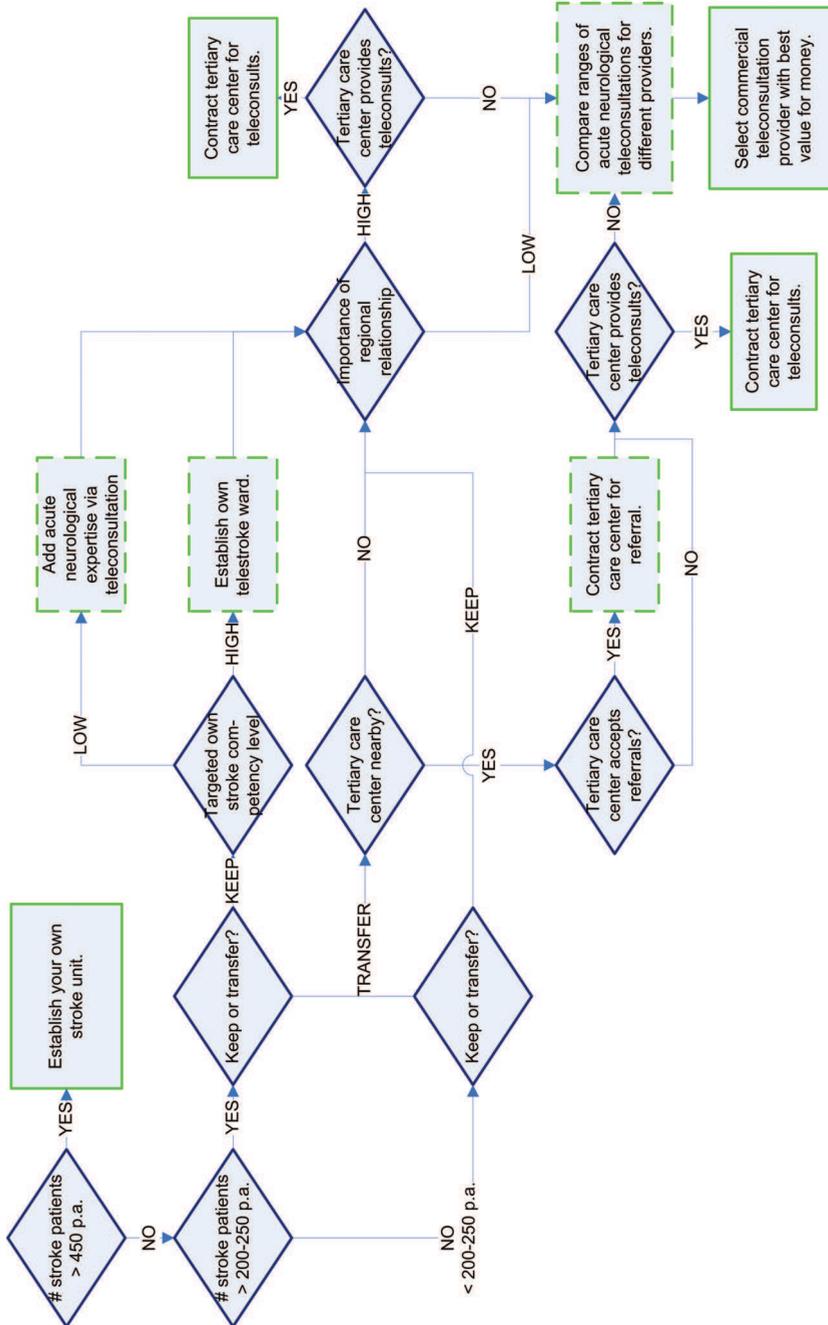


Fig. 6. Telestroke network concept decision algorithm.

part of a tertiary care center including neurosurgery and neuroradiology. Pondering the telemedicine options for stroke patient care, the hospital management may proceed along the decision tree in the following manner.

First of all, from the top level decision it is clear that it is not reasonable to arrange a full-blown stroke unit in this primary care hospital due to insufficient stroke incidence. Second, the hospital management realizes that it cannot reasonably transfer all acute stroke patients, since (1) that would mean a major reduction in revenue and (2) the potential referral stroke unit is too far away for the majority of patients to benefit. Thus, the general decision is to keep acute stroke patients. However, the physicians worry about their insufficient treatment options for severe acute strokes possibly requiring neurointervention, and would like to implement a bridging concept. Therefore they contact the tertiary care center and suggest to establish a neurological teleconsultation link in combination with a fast track (helicopter based) patient transfer option only for those severe acute stroke patients benefiting from neurointervention – maybe a few per month. The better the personal relationship to the tertiary care center already is, the more successful this endeavor will be in practice. The stroke unit in question is willing to cooperate within this setting, but they are unable to comply with any additional patient transfer requests. In order to provide supplemental neurological expertise to all patients presenting with acute neurological symptoms, the hospital management contacts a nationwide commercial provider of teleconsultations in this field. Thus, they treat different types of stroke patients according to different telestroke network concepts – and may even be using the same technology for both types of teleconsults.

Besides, the hospital's clinical directors have already been thinking about hiring a part-time speech therapist and an occupational therapist anyway, so with some stroke expert advice available these resources could be effectively used for acute stroke patients, too. Due to constraints in the hospital's staffing, however, it is impossible to arrange a completely certified telestroke ward, so the local stroke infrastructure is just improved by these two rehabilitation measures.

The clinical scenario described here is easily reflected in the triangular classification scheme presented above. The required primary care hospital competency is on an intermediate level, same as the clinical indication spectrum and the service spectrum provided: for a small number of severe stroke patients there is an intermediate spectrum of services provided (teleconsultation plus possible subsequent transfer within a bridging concept), and for all other patients with neurological symptoms, the teleneurological consult is available. So this scenario corresponds to a point close to the center of the diagram, as depicted in Figure 4 (right).

## 6. Discussion and conclusion

In this study, we present a novel approach to telestroke network design from the viewpoint of a primary care hospital seeking to improve its stroke patient care. The central conclusion of our systematic structural analysis is that a continuum of possible combinations of established network types is both feasible in principle and reasonable in practice. This conclusion constitutes a fundamental paradigm shift to the effect that telestroke network concepts do not compete with but rather complement each other.

Many primary care hospitals may well have refrained from implementing telestroke so far, because they felt that currently established network types would not meet their needs. Our

results indicate, however, that they can in fact tailor a telemedical solution to their needs, combining features from a full range of different telestroke network types. Both in the systematic telestroke network taxonomy and by using the decision algorithm, such combinations or mixtures of telemedical concepts arise quite naturally.

Hence, from a health-economic point of view, many different kinds of primary care hospitals could benefit from implementing individual telestroke care solutions, and there is room for much more widespread applications. These unsatisfied customer needs should be met by designing innovative business models for telemedicine taking into account the problems arising from an ageing population and the projected increasing shortage of neurological experts in rural areas.

There are certain limitations to our study. Our formal representation of telestroke networks is based upon the identification of the central telemedicine protagonist roles and their association with semi-quantitative parameters. This association is not unique and different parameters could be constructed, but we are confident to have captured the most relevant protagonist properties in our model.

Moreover, the choice of network type as described in our triangular classification is not the single determinant of which specific measures the individual primary care hospital needs to implement in terms of local infrastructure and global telemedicine. These measures rather depend upon a number of additional aspects that go way beyond the presented telestroke classification scheme. A variety of environmental elements have to be taken into account: national, demographic, socioeconomic, infrastructural and regional factors like stroke incidence, hospital and physician availability or health care reimbursement regulations.

Complementary to these issues, each primary care hospital must take its individual economic perspective into account. It would therefore be highly desirable to determine the costs incurred and revenue generated by associating with specific telestroke network services. Any utility function derived from these costs and revenues will depend on the three parameters introduced in section 3, and can be pictured as a landscape above the triangular base, so that the network concept optimization task with respect to this utility function amounts to determining the minima (valleys) in this landscape. However, in order to actually perform such an optimization, quantitative economic data has to be collected first. Furthermore, the future savings by telestroke interventions in terms of healthcare and nursing costs remain quantitatively vague. Here, health economic studies are required to determine the actual added value of telestroke intervention and finally permit an economic comparison between different telestroke models.

## 7. Acknowledgement

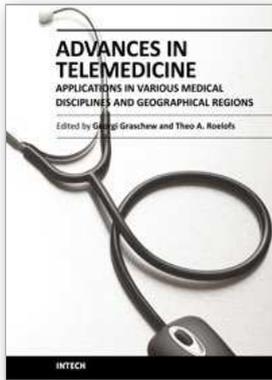
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## **Advances in Telemedicine: Applications in Various Medical Disciplines and Geographical Regions**

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Innovative developments in information and communication technologies (ICT) irrevocably change our lives and enable new possibilities for society. Telemedicine, which can be defined as novel ICT-enabled medical services that help to overcome classical barriers in space and time, definitely profits from this trend. Through Telemedicine patients can access medical expertise that may not be available at the patient's site. Telemedicine services can range from simply sending a fax message to a colleague to the use of broadband networks with multimodal video- and data streaming for second opinioning as well as medical telepresence. Telemedicine is more and more evolving into a multidisciplinary approach. This book project "Advances in Telemedicine" has been conceived to reflect this broad view and therefore has been split into two volumes, each covering specific themes: Volume 1: Technologies, Enabling Factors and Scenarios; Volume 2: Applications in Various Medical Disciplines and Geographical Regions. The current Volume 2 is structured into the following thematic sections: Cardiovascular Applications; Applications for Diabetes, Pregnancy and Prenatal Medicine; Further Selected Medical Applications; Regional Applications.

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