

Root Cause Exploration of DNT Delay in Patients with Acute Ischemic Stroke: A Mixed-Method Study Based on the Experience of Front-Line Nurses in Stroke Green Channel

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Abstract: Anchored in the perspective of sociotechnical system theory, this study combines quantitative time data with the qualitative experience of front-line nurses to analyze the core nodes, multi-level root causes and coupling mechanism of door-to-needle time (DNT) delay in patients with acute ischemic stroke (AIS), so as to provide theoretical basis and practical paths for the systematic optimization of stroke green channel. An explanatory sequential mixed-method study design was adopted. The first phase was a retrospective quantitative study, which enrolled 156 AIS patients who received intravenous thrombolysis in a tertiary grade A hospital from January 2022 to June 2023, and identified the core delay links through time disassembly and descriptive statistics. The second phase was a qualitative study, in which 14 front-line nurses working in the stroke green channel were interviewed with semi-structured in-depth interviews focusing on the core delay links. Colaizzi phenomenological analysis method was used for coding and theme extraction to construct an explanatory model of delay mechanism. The results showed that the median DNT was 58 min, among which imaging examination, informed consent and waiting for test results accounted for the highest proportion of time, 24.1%, 20.7% and 18.3% respectively, which were the core key nodes of DNT delay. The qualitative study extracted four levels of root causes: structural layer, process layer, subject layer and cultural layer. Its mechanism is manifested as follows: structural resource allocation defects lay the basic boundary of delay, cross-departmental process breakpoints form the transmission path of delay, differences in subject competence and decision-making amplify the degree of delay, and implicit culture and institutional environment shape the behavioral logic of delay from the deep level. The four levels eventually form system-level efficiency

loss through the mismatched coupling between technical subsystem and social subsystem. DNT delay is not an efficiency problem of a single link, but the result of multi-level coupling failure of "structure-process-subject-culture" in the stroke treatment sociotechnical system. To shorten DNT, we cannot only rely on single-point speed improvement, but must promote the collaborative optimization of both technical and social dimensions from the perspective of system reconstruction.

Keywords: Acute Ischemic Stroke; Door-to-Needle Time; Stroke Green Channel; Front-Line Nurses; Mixed-Method Study; Coupling Mechanism; Sociotechnical System

1. Introduction

Stroke is the leading cause of death and disability in adults in China, among which acute ischemic stroke accounts for more than 70% of all strokes, imposing a heavy disease burden [1]. Intravenous thrombolysis with recombinant tissue plasminogen activator (rt-PA) within 4.5 hours of onset is the first-line treatment recommended by domestic and international guidelines. For every 1-minute delay in treatment, approximately 1.9 million neurons are lost in patients, indicating extremely high time sensitivity [2-3].

DNT, defined as the time from patient arrival at the hospital gate to the start of thrombolytic drug infusion, is the core quality indicator for evaluating the efficiency of stroke green channel treatment. Both domestic and international guidelines clearly require $DNT \leq 60$ min, with an advanced target of ≤ 45 min [4]. In recent years, the construction of stroke centers in China has developed rapidly, and the national intravenous thrombolysis rate and treatment efficiency have continued to improve. However, the DNT compliance rate is still uneven across the country. The median DNT in some hospitals still exceeds 60 min, and delay is widespread. Moreover, after repeated optimization, it often falls into a

bottleneck and is difficult to achieve a qualitative breakthrough [5].

Existing studies on influencing factors of DNT are mostly pure quantitative or pure qualitative research: quantitative studies mostly focus on objective variables such as patient demographic characteristics and visiting time, which can locate delay links but are difficult to reveal the deep mechanism [6]; qualitative studies mostly explore barriers based on nurses' experience, but mostly stay at the list of factors, lacking systematic explanation of the interaction between factors [7]. More importantly, most existing studies regard DNT delay as an efficiency problem of a single link, and have not yet analyzed the essence of its multi-level coupling effect from the perspective of system theory.

Sociotechnical system (STS) theory points out that organizational operation efficiency is not determined by technology or a single element, but by the interaction and collaborative matching between the technical subsystem (hardware, structure, process) and the social subsystem (personnel, culture, institution), and the adaptability between the two fundamentally determines system performance [8]. Introducing this theoretical perspective, this study adopts a mixed quantitative and qualitative research design. It first locates the core delay nodes through objective data, and then digs into the multi-level root causes and action mechanism behind them combined with the experience of front-line nurses, taking into account the objectivity of conclusions and theoretical depth, so as to provide a more systematic practical basis for the process reengineering of stroke green channel.

2. Research Objects and Methods

2.1 Research Objects

This study is divided into two phases, and the research objects are as follows:

- Quantitative phase: Using retrospective sampling, 156 patients with acute ischemic stroke who received intravenous thrombolysis in Pengshui Miao and Tujia Autonomous County People's Hospital from January 2022 to June 2023 were selected. Inclusion criteria: met the diagnostic criteria for acute ischemic stroke, received rt-PA intravenous thrombolysis within 4.5 hours of onset, and had complete clinical time node data.
- Qualitative phase: Using purposive

sampling, front-line emergency nurses working in the hospital's stroke green channel were selected as research objects. Inclusion criteria: holding a nurse practice certificate, working in the stroke green channel for ≥ 1 year, having fully participated in the intravenous thrombolysis treatment process of AIS patients, and volunteering to participate in this study. Nurses in further education, interns and administrative staff who do not directly participate in front-line treatment were excluded. The sample size was determined by data saturation, and 14 nurses were finally included.

2.2 Research Methods

An explanatory sequential mixed-method study design was adopted. Quantitative research was first carried out to locate key delay links, and then qualitative research was conducted guided by the results to dig into the root causes. The two phases are connected in an orderly manner and complement each other.

2.2.1 Quantitative research phase

Time node data of patients' thrombolysis treatment were collected retrospectively through the hospital information system, including triage time, doctor consultation time, CT examination completion time, test result return time, informed consent signing time, drug infusion start time, etc. The time consumption of each link and its proportion in the total DNT were calculated. Descriptive statistical analysis was used to locate the core delay nodes with the highest proportion and analyze the time structure characteristics of each link.

2.2.2 Qualitative research phase

Guided by the core delay links identified in the quantitative research, a semi-structured interview outline was designed. One-on-one in-depth interviews were conducted with front-line nurses around core topics such as delay causes, implementation barriers, action logic and improvement suggestions. The interviews were conducted in a quiet and private environment, with a single interview duration of 30–45 min. The whole process was recorded simultaneously, and transcribed into text materials in time after the interview, with personal information anonymized.

Colaizzi phenomenological analysis method was used to analyze the text materials. Core themes were gradually extracted through coding, classification and refinement, and the logical relationship between themes was further sorted

out. An explanatory model of delay mechanism was constructed combined with sociotechnical system theory [9]. Two researchers completed the coding independently and cross-checked each other. In case of disagreement, consensus was reached through group discussion of the research group to ensure the credibility of the analysis results.

3. Research Results

3.1 Quantitative Research Results: Time Consumption and Structural Characteristics of Each DNT Link

The DNT of 156 patients ranged from 32 to 115 min, with a median of 58 min, and the compliance rate of $DNT \leq 60$ min was 56.5%. DNT was disassembled into 6 main links, and the time consumption and proportion of each link are shown in Table 1.

Table 1. Time Consumption and Proportion of Each DNT Link in Patients with Acute Ischemic Stroke

Link	Median time consumption (min)	Proportion in total DNT
Triage and initial assessment	8.5	14.7%
Doctor consultation and order placing	6.0	10.3%
Imaging examination (CT + film reading)	14.0	24.1%
Waiting for test results	10.6	18.3%
Informed consent signing	12.0	20.7%
Drug preparation and infusion	6.5	11.2%

The results showed that imaging examination, informed consent and waiting for test results were the three links with the longest time consumption, accounting for 63.1% of the total DNT in total, which were the core key nodes of DNT delay. From the perspective of time structure, the three correspond to different types of delay respectively: imaging examination belongs to physical bottleneck delay, limited by equipment and human productivity; waiting for test results belongs to information breakpoint delay, and subsequent processes depend on pre-order results; informed consent belongs to decision stuck point delay, depending on the subjective judgment of patients and their families.

3.2 Qualitative Research Results: Multi-Level Root Causes and Action Logic of Delay

Focusing on the above three core delay nodes, through in-depth analysis of interview data from 14 nurses, 4 core themes and 11 sub-themes were

extracted, corresponding to the four levels of DNT delay, fully presenting the deep root causes and conduction logic of delay.

3.2.1 Process layer: process breakpoints in multi-departmental collaboration mechanism

The vast majority of nurses stated that the green channel has not yet achieved real "seamless connection", and the collaborative breakpoints across multiple departments and links are the most direct objective cause of delay in imaging and test links.

- Inconsistent cognition of cross-departmental priority: Stroke treatment involves multiple departments such as emergency department, imaging department, laboratory department, neurology department and pharmacy, but the implementation standards of "stroke priority" are not unified among departments. CT rooms and laboratory departments undertake various types of emergency patients at the same time, and stroke patients do not obtain substantive priority, so queuing and waiting are common. Such process breakpoints do not exist in isolation, but amplify the time loss of imaging and test links step by step through the conduction chain of "waiting - queuing - re-waiting", and ultimately directly push up the total DNT duration [10].

- Lack of pre-hospital and in-hospital connection mechanism: The 120 pre-hospital early warning mechanism is not fully implemented. The hospital cannot start examination preparation in advance. Patients only start to make CT appointments and issue test orders after arriving at the hospital, which is equivalent to starting the process from scratch and adding waiting time for no reason.

- Insufficient information support capability: The information systems of various departments are independent of each other, and examination results cannot be automatically pushed to the emergency room. Nurses need to repeatedly query the system or inquire by telephone, which increases communication costs and waiting time. The "data islands" formed by information fragmentation make process connection lose technical support and can only rely on manual compensation.

3.2.2 Structural layer: insufficient allocation and competence adaptation of human resources

The structural allocation of manpower and resources is the basic boundary of process operation and the most rigid constraint strongly felt by front-line nurses.

- Lack of full-time stroke nurse positions:

Most hospitals have not set up full-time nurses for stroke green channel. Emergency nurses simultaneously undertake the treatment of ordinary emergency patients, making it difficult to follow up the whole process of stroke patients. The structural shortage of manpower allocation makes nurses become the "rigid bottleneck" in the process. Fluctuations in any link will be amplified due to insufficient manpower, forming the effect of "one person absent, the whole line slows down".

- **Overloaded post workload:** Nurses not only need to complete nursing operations, but also undertake a lot of cross-departmental coordination, document writing and other work. Their energy is seriously dispersed, and process connection gaps are prone to occur. When facing multiple emergency patients at the same time, the time priority of stroke patients is easily diluted.

- **Insufficient team competence and tacit understanding:** Junior nurses are not familiar with the thrombolysis process, there is a lack of multidisciplinary joint drills, and there is a lack of tacit cooperation among various positions, resulting in low communication efficiency. Competence differences are directly transformed into time differences. The same process implemented by different teams can result in a DNT difference of more than 10 minutes.

3.2.3 Subject layer: uncontrollable factors related to patients and their families

The cognitive and decision-making behaviors of patients and their families are the main reasons for the delay in the informed consent link, and also important variables that nurses cannot fully control.

- **Informed consent decision dilemma:** Family members have insufficient cognition of thrombolytic therapy and excessive worry about bleeding risk. The decision-making process is lengthy, often requiring repeated consultation and waiting for family members to arrive and sign, which takes up a lot of time. As an uncertain variable at the end of the process, patient-related factors often break the preset time rhythm, and because of their uncontrollability, they become the most difficult delay source for nurses to intervene.

- **Limited patient condition and compliance:** Severe patients are restless and unconscious, unable to cooperate with examinations, requiring additional sedation and restraint time, which prolongs the time of imaging examination and other links.

- **Economic and trust concerns:** Some family members do not trust the policy of "treatment first, payment later" and insist on paying first before treatment, leading to process stagnation.

3.2.4 Cultural layer: constraints in implicit culture and institutional environment

The cognitive and psychological factors of the medical staff group are hidden root causes of delay that are easily overlooked. They penetrate into all links and shape the behavioral logic from the bottom.

- **Insufficient cognition of time urgency:** Non-stroke specialist positions do not have a deep understanding of the concept of "time is brain", and do not pay enough attention to the priority of green channel, believing that "a few minutes later does not matter". The implicit constraints at the cultural level penetrate into every link of the process, and slow down the overall treatment rhythm from the bottom by affecting individual behavior priority. It is the most difficult to quantify and the most easily overlooked deep root cause.

- **Defensive medical psychology:** Some medical staff are too conservative in the process to avoid medical risks, overemphasize the screening of contraindications, and repeatedly check the process, which sacrifices treatment time to a certain extent. This defensive psychology is essentially an individual rational choice under the lack of risk sharing mechanism, which cannot be fundamentally changed only by emphasizing "speed improvement".

4. Discussion

4.1 Temporal Structure and System Conduction Effect of Core Delay Nodes

The quantitative results of this study show that imaging examination, informed consent and waiting for test results are the three core links of DNT delay, accounting for more than 60% in total, which is basically consistent with the results of similar studies at home and abroad [6,11]. However, further analysis from the time structure shows that the three links are not simply "the longest time consumption", but are located in different key positions of the process respectively, with different types of delay conduction effects: imaging examination is a physical bottleneck, with limited equipment and technician productivity, and once congested, a queue will be formed, and the delay is cumulative; waiting for test results is an information breakpoint,

subsequent processes cannot proceed without results returned, and the delay is blocking; informed consent is a decision stuck point, depending on the subjective judgment of patients, and the delay is uncertain.

The superposition of three different types of delay forms a composite effect of "bottleneck congestion - breakpoint stagnation - stuck point delay", which is also why local optimization often has little effect — only compressing the time of a single link cannot break the coupling effect of different types of delay. It is worth noting that the informed consent link accounts for 20.7% of the time, second only to imaging examination. This suggests that with the continuous optimization of in-hospital hardware processes, the compressible technical space on the medical side is gradually shrinking, while the proportion of social delay caused by patient decision-making will continue to rise, and will become the main contradiction restricting DNT compliance in the future [5].

4.2 Multi-level Coupling Mechanism of DNT Delay: Interpretation Based on Sociotechnical System

The four themes extracted based on nurses' experience in this study essentially correspond to the constituent elements of technical subsystem and social subsystem in sociotechnical system theory: structural layer and process layer belong to the category of technical subsystem, while subject layer and cultural layer belong to the category of social subsystem. The occurrence of DNT delay is the coupling result of internal element imbalance and matching failure between the two subsystems. This mechanism explains at the system level why DNT delay is difficult to be cured by single-point rectification [8].

The structural layer is the hardware foundation of the technical subsystem, which defines the efficiency boundary of delay. Structural factors such as fragmented information systems, lack of full-time positions and unreasonable spatial layout are the underlying hardware configuration of system operation, which directly determines the maximum efficiency boundary of process operation. As far as this study is concerned, the disconnected information systems and the absence of full-time stroke nurses fundamentally determine that the process must rely on manual coordination and manpower balance, which naturally has an efficiency upper limit. This is the deep structural constraint that makes it difficult for DNT to break through the advanced target of

45 minutes. The "technological determinism" perspective in sociotechnical system theory points out that the inherent defects of technological structure cannot be completely made up by personnel efforts, which also confirms the findings of this study: without changing the underlying structure of resource allocation, only optimizing the operation process can only achieve marginal improvement and cannot achieve qualitative leap.

The process layer is the operation rule of the technical subsystem, which constitutes the transmission path of delay. Process breakpoints such as inconsistent cross-departmental priorities and lack of pre-hospital and in-hospital connection are defects in the program rules of system operation, which transform the resource constraints of the structural layer into actual time loss. The multi-departmental attribute of stroke treatment determines the collaborative dependence of the process. The priority deviation of any department will be transmitted to the entire DNT cycle through the process chain, forming a typical "barrel effect" — the speed of the entire green channel is not determined by the fastest link, but by the link with the worst collaboration. This is essentially the internal friction of the system caused by inconsistent rules and mismatched interfaces within the technical subsystem, and it is also the level where most hospitals' green channel optimization efforts are most often focused but also most likely to reach the ceiling [10].

The subject layer is the active carrier of the social subsystem, which amplifies the degree difference of delay. The competence load of nurses and the decision-making behavior of patients and their families, as active subjects in the system, directly affect the actual time consumption of each link. Under the same process configuration, the execution efficiency of senior nurses and junior nurses can differ by more than double; the speed of family decision-making can also cause a time difference of more than ten minutes. Differences at the subject level make DNT delay show obvious situational volatility, which is difficult to be completely eliminated through standardized processes. Sociotechnical system theory emphasizes that people are the most active variables in the system, and the effectiveness of technical system must ultimately be realized through human behavior. Insufficient subject competence and cognition will directly reduce the design efficiency of technical system.

The cultural layer is the deep logic of the social subsystem, which determines the persistence inertia of delay. Insufficient cognition of time urgency and defensive medical psychology, as an implicit institutional culture, are the value core of the social subsystem, shaping the behavior choices of all subjects from the bottom. The fact that auxiliary departments do not attach importance to time priority is essentially that stroke treatment culture has not been internalized by all staff; the excessive conservatism of medical staff is essentially a rational choice under the lack of risk sharing mechanism. The influence of cultural level is silent but ubiquitous, and it is the underlying driving force behind all explicit factors. This also explains why many hospitals have complete institutional processes, but the actual implementation effect is discounted — the rules of technical subsystem can be quickly established, but the cultural reshaping of social subsystem requires a long process.

The four levels do not function independently, but are nested and progressive layer by layer: structure constrains process, process affects subject, subject reflects culture, and culture reacts on structure and process; technical subsystem provides operation framework for social subsystem, and social subsystem provides power support for technical subsystem. The higher the matching degree between the two, the higher the system efficiency; otherwise, continuous efficiency loss will occur. The complex picture of DNT delay is precisely the concentrated embodiment of the coupling failure of multiple elements in the two subsystems. This also explains why the DNT problem is repeatedly treated but difficult to be cured — previous optimizations mostly stay at the process adjustment of the process layer, without touching the resource allocation of the structural layer and the institutional logic of the cultural layer, so naturally it is difficult to achieve a qualitative breakthrough.

4.3 Theoretical Value and Practical Significance of the Front-Line Nurse Perspective

As the full-process executors of the green channel, front-line nurses are the only role that connects the four levels of structure, process, subject and culture. They can not only see the objective breakpoints of the process, but also perceive the implicit cultural constraints. This study opens the "black box" of DNT delay

through the perspective of nurses. Its theoretical value lies in breaking through the previous "factor list" research paradigm, taking sociotechnical system theory as the anchor point, constructing a multi-level coupling delay mechanism explanation model, and raising DNT delay from an "operational efficiency problem" to a "system governance problem", enriching the theoretical perspective of stroke treatment management.

At the practical level, this perspective also reminds us that process optimization cannot only rely on top-down system implementation, but must fully listen to the experience and demands of front-line executors. Many systems that seem reasonable at the management level will encounter various situational obstacles in front-line implementation, and these obstacles are the reality that nurses face every day. Only by combining top-level design with front-line experience can we formulate optimization schemes that are truly implementable and effective.

4.4 Optimization Path from the Perspective of System Reconstruction

Based on the above sociotechnical system coupling mechanism, shortening DNT can no longer follow the old path of "single-point optimization and scattered rectification". We must start from system reconstruction, simultaneously promote the upgrading of technical subsystem and the optimization of social subsystem, implement policies at different levels and promote them collaboratively.

First, build a solid structural foundation and upgrade the hardware of technical subsystem. Break the underlying constraints from the perspective of resource allocation, set up full-time stroke nurse positions to realize special personnel for special posts and full-process management; promote the construction of an integrated information platform for stroke treatment, realize automatic push of examination results and automatic timing and early warning of nodes; place thrombolytic drugs in the emergency rescue room in advance to eliminate the physical distance loss of the drug taking link. Through structural resource upgrading, fundamentally improve the efficiency boundary of the technical system and provide hardware support for overall speed improvement [12].

Second, break through process barriers and unblock the interfaces of technical subsystem. Break through cross-departmental collaborative

breakpoints, establish a stroke treatment priority assessment mechanism, incorporate "stroke priority" into the performance assessment of auxiliary departments such as imaging, laboratory and pharmacy, and unify system operation rules; improve the pre-hospital and in-hospital early warning linkage mechanism, realize early push of patient information during 120 transportation and early start of preparation in hospital; implement the "parallel diagnosis and treatment" mode, complete informed consent, drug preparation and other work simultaneously while waiting for CT results, change serial process to parallel process, and compress the overall time. Reduce system internal friction through standardization of process interfaces [10].

Third, empower the subject and activate the carrier of social subsystem. On the one hand, strengthen the construction of nurses' professional competence, carry out normalized multidisciplinary joint drills, improve team cooperation tacit understanding, and reduce efficiency loss caused by differences in subject competence; on the other hand, optimize the communication mode with patients and their families, produce standardized and visual thrombolysis informed consent education tools, carry out stroke treatment popular science in advance, and reduce the decision-making difficulty and time cost of family members. Through empowering both ends of the subject, make human factors become amplifiers of efficiency rather than bottlenecks.

Fourth, shape the cultural soul and reshape the core of social subsystem. Build a full-staff stroke treatment culture, strengthen the concept of "time is brain", and internalize time priority into the behavioral consciousness of each post; at the same time, establish and improve the medical risk sharing mechanism, clarify the exemption circumstances of adverse events in thrombolytic treatment, reduce the defensive psychology of medical staff, and encourage bold speed improvement under the premise of norms. Through the dual guidance of culture and system, stimulate the endogenous power of efficiency improvement from the deep level, and realize the deep matching between technical system and social system.

5. Research Limitations and Prospects

This study is a single-center study, and both quantitative data and qualitative samples are from the same hospital, with certain limitations in

representativeness. The constructed multi-level coupling mechanism still needs further verification by more large-sample multi-center studies. In the future, multi-center mixed-method studies can be carried out, including multiple perspectives such as doctors, medical technicians and patients' families, to more comprehensively analyze the complex causes of DNT delay; at the same time, intervention studies can be carried out to design system optimization schemes based on sociotechnical system theory and verify their practical application effects.

6. Conclusion

DNT delay in patients with acute ischemic stroke is essentially the result of multi-level coupling failure of "structure-process-subject-culture" in the stroke treatment sociotechnical system, rather than an efficiency problem of a single link or a single department. Imaging examination, informed consent and waiting for test results are the three core delay nodes, behind which correspond to three different types of time loss: physical bottleneck, decision stuck point and information breakpoint respectively. Deep down, it is the joint effect of insufficient hardware and poor interfaces of the technical subsystem, as well as subject absence and cultural lag of the social subsystem.

This study adopts a mixed quantitative and qualitative design, and constructs a multi-level action mechanism model of DNT delay based on sociotechnical system theory through the full-process perspective of front-line nurses, breaking through the limitations of factor listing in previous studies. The core way to shorten DNT lies in shifting from single-point optimization to system reconstruction, simultaneously promoting the structural upgrading and process optimization of the technical subsystem, as well as subject empowerment and cultural reshaping of the social subsystem. Through two-dimensional collaborative efforts, we can truly build an efficient, smooth and sustainable stroke green channel system, and maximize the treatment time for patients.

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