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Clinical Observation of Minimally Invasive Puncture Drainage Assisted by Robot Navigation for the Treatment of Hypertensive Cerebral Hemorrhage

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Abstract: *Objective:* To study the clinical effect of robot navigation-assisted minimally invasive puncture drainage treatment for hypertensive intracerebral hemorrhage. Method: 80 patients with hypertensive intracerebral hemorrhage who received treatment in our hospital from February 2024 to February 2025 were selected and randomly divided into two groups using a random number table, with 40 patients in each group. The conventional puncture group received traditional minimally invasive puncture drainage treatment, while the robot navigation group received minimally invasive puncture drainage treatment with the assistance of robot navigation. The treatment effects of the two groups were compared. Result: The robot navigation group had better surgical-related indicators, lower neurological deficit scores, and fewer complications ($P < 0.05$). *Conclusion:* The application of robot navigation-assisted minimally invasive puncture drainage therapy for hypertensive intracerebral hemorrhage can optimize surgical indicators, improve neurological function, and reduce the probability of complications.

Keywords: Robot navigation; Hypertensive cerebral hemorrhage; Minimally invasive puncture drainage; Neurological function; complication

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1. Introduction

Hypertensive intracerebral hemorrhage is a common and critical condition in clinical practice, mainly caused by long-term hypertension leading to hyalinization and fibrinoid necrosis of small cerebral arteries. When blood pressure suddenly rises sharply, these diseased blood vessels are prone to rupture and bleed, leading to the formation of intracranial hematomas [1]. The onset of this disease is extremely rapid, usually taking only a few minutes to a few hours from the onset to the appearance of significant symptoms, and the condition progresses rapidly, which may lead to serious symptoms such as consciousness disorders and limb paralysis in a short period of time. If effective treatment measures are not taken promptly, it will not only leave serious neurological sequelae for patients, but may even directly endanger their life safety. At present, the core goal of treating hypertensive intracerebral hemorrhage in clinical practice is to clear the intracranial hematoma as soon as possible, reduce the pressure of the hematoma on surrounding brain tissue, lower intracranial pressure, thereby reducing ischemic and hypoxic damage to brain tissue, and create favorable conditions for the recovery of neurological function.

Among the various methods for treating hypertensive intracerebral hemorrhage, minimally invasive puncture drainage has become a commonly used treatment method due to its advantages of minimal trauma, relatively simple operation, and minimal impact on the patient's overall condition. Especially for elderly patients with poor physical condition who cannot afford craniotomy surgery, it is the preferred option. However, traditional minimally invasive puncture drainage surgery mainly relies on doctors to determine the location and size of the hematoma based on the patient's head CT image, and then determine the puncture point and path based on their own clinical experience. The entire operation process is not accurately guided, so it is easy to cause inaccurate puncture due to factors such as insufficient doctor experience, deviation in hematoma location judgment, or slight movement of the patient's head. With the continuous development of medical technology, robot navigation technology is gradually being used in neurosurgery. This technology relies on advanced imaging and computer processing systems to perform three-dimensional reconstruction of the patient's intracranial structure, helping doctors to more intuitively and accurately understand the location of the hematoma and the distribution of important nerves and blood vessels around it. It can also guide surgical operations in real time to allow the puncture needle to accurately reach the hematoma site according to the pre-set optimal path. Based on this background, this study mainly observes the clinical role of robot navigation-assisted minimally invasive puncture and drainage treatment for hypertensive intracerebral hemorrhage.

2. Data and methods

2.1. General information

Eighty patients with hypertensive intracerebral hemorrhage who received treatment in our hospital from February 2024 to February 2025 were randomly divided into a conventional puncture group and a robot navigation group using a random number table method, with 40 patients in each group. There were 22 males and 18 females in the routine puncture group, with ages ranging from 45 to 78 (58.62 ± 5.34) years old; There were 21 males and 19 females in the robot navigation group, aged 46–79 (59.05 ± 5.28) years old. Two groups are comparable, $P > 0.05$. Inclusion criteria: (1) Meet the diagnostic criteria for hypertensive intracerebral hemorrhage; (2) The time from onset to admission is less than 24 hours; (3) Patients and their families give informed consent. Exclusion criteria: (1) Combination of severe liver, liver, and kidney diseases; (2) Coagulation dysfunction; (3) Patients with brainstem hemorrhage.

2.2. Method

The conventional puncture group adopts traditional minimally invasive puncture drainage treatment. The doctor determines the puncture point and puncture path based on the imaging examination results. After local anesthesia, the puncture operation is carried out, and a drainage tube is inserted and connected to the drainage device. After surgery, the drainage speed is adjusted according to the patient's condition, and regular head CT scans are conducted to observe the clearance of the hematoma.

The robot navigation group carries out minimally invasive puncture and drainage treatment with the assistance of robot navigation. Before surgery, the patient's head CT scan is performed, and the image data is imported into the robot navigation system. The system constructs a three-dimensional model based on the data and plans the optimal puncture path. During the operation, the robot navigation system guides the doctor in real-time to ensure that the puncture needle accurately reaches the hematoma site. The subsequent drainage operation is consistent with the conventional puncture group.

2.3. Observation indicators

Compare the surgical time, intraoperative blood loss, hematoma clearance rate, NIHSS score before and after intervention, and the probability of complications between the two groups.

2.4. Statistical methods

Use SPSS 24.0 to analyze the data. Measurement data t-test; Count data chi-square test. $P < 0.05$ represents a significant difference.

3. Results

3.1. Comparison of surgical-related indicators between the two groups

The robot navigation group had shorter surgical time, less intraoperative bleeding, and higher hematoma clearance rate ($P < 0.05$), as shown in **Table 1**.

3.2. Comparison of NIHSS scores between two groups before and after intervention

After intervention, the scores of the robot navigation group were lower than those of the conventional puncture group ($P < 0.05$), as shown in **Table 2**.

3.3. Comparison of the incidence of complications between the two groups

The probability of complications in the robot navigation group was lower than that in the conventional puncture group ($P < 0.05$), as shown in **Table 3**.

Table 1. Comparison of surgical-related indicators between two groups (mean ± SD)

Group	Operation time (min)	Intraoperative blood loss (mL)	Hematoma clearance rate (%)
Conventional puncture group (n = 40)	58.45 ± 8.62	42.36 ± 7.58	72.58 ± 6.34
Robot navigation team (n = 40)	35.28 ± 6.15	21.45 ± 5.26	89.63 ± 5.72
t	13.839	14.334	12.628
P	0.000	0.000	0.000

Table 2. Comparison of NIHSS scores between the two groups before and after intervention (mean ± SD, points)

Group	Pre-intervention evaluation	Post-intervention score
Conventional puncture group (n = 40)	18.65 ± 3.24	10.82 ± 2.56
Robot navigation team (n = 40)	18.72 ± 3.18	6.35 ± 2.14
t	0.098	8.473
P	0.923	0.000

Table 3. Comparison of incidence of complications between two groups [n(%)]

Group	Intracranial rebleeding	Infection	Nerve injury	Overall incidence rate [n(%)]
Conventional puncture group (n = 40)	3 (7.50)	3 (7.50)	2 (5.00)	8 (20.00)
Robot navigation team (n = 40)	0 (0.00)	1 (2.50)	0 (0.00)	1 (2.50)
χ^2				4.507
P				0.034

4. Discussions

Hypertensive intracerebral hemorrhage, as one of the most serious complications of hypertension patients, has an extremely complex pathophysiological process and involves multidimensional mechanisms of damage to brain tissue. The intracranial hematoma formed after the rupture and bleeding of cerebral blood vessels will exert mechanical compression on surrounding brain tissue in a short period of time. This compression directly leads to a decrease in local cerebral blood perfusion, triggering ischemia and hypoxia reactions. At the same time, during the process of hematoma decomposition, a large amount of harmful substances, such as iron ions and various inflammatory factors produced by hemoglobin decomposition, will be released, which will further exacerbate the inflammatory response and oxidative stress damage of brain tissue, thereby inducing neuronal apoptosis and brain tissue edema. Brain edema will aggravate the increase of intracranial pressure, ultimately forming a vicious cycle of "hematoma compression ischemia hypoxia brain edema intracranial pressure increase". If this cycle is not broken in a timely manner, the extent of brain tissue damage will continue to expand, and neurological dysfunction will further deteriorate. Therefore, the prompt and safe removal of intracranial hematoma in the treatment of hypertensive intracerebral hemorrhage is the core link to block the progression of pathological damage and improve patient prognosis. Minimally invasive puncture and drainage surgery is a treatment technology developed around this critical need. However, the long-standing problem of insufficient precision in traditional minimally invasive puncture and drainage surgery has always been an important factor restricting its therapeutic effect.

The results of this study showed that the surgical time of the robot navigation group was significantly shorter than that of the conventional puncture group, and the intraoperative blood loss was also significantly less than that of the conventional puncture group. This data fully demonstrates the outstanding advantages of robot navigation technology in improving surgical efficiency and safety. From the analysis of the surgical operation process, it can be seen that traditional minimally invasive puncture surgery requires doctors to repeatedly read the patient's head CT images and construct the hematoma spatial position in their mind, and then determine the puncture point and depth based on clinical experience. During this process, doctors often need to adjust the puncture angle and direction multiple times to approach the ideal puncture position, which not only prolongs the surgical time but also easily leads to damage to surrounding brain tissue and small blood vessels by the puncture needle, thereby increasing the risk of intraoperative bleeding. The robot navigation team performed a cranial CT scan before surgery. After scanning and obtaining detailed data of the patient's intracranial structure, the navigation system can automatically process this data and construct a clear 3D image model. Doctors can intuitively observe the size, shape, and relative position relationship of the hematoma with surrounding important nerves and blood vessels on the model, and then accurately plan the optimal puncture path, including the specific coordinates of the puncture point, puncture angle, and puncture depth based on this information. During the surgical operation, the navigation system will track the position of the puncture needle in real time and compare it with the preset puncture path, provide timely feedback on deviation information to the doctor, and guide adjustment, ensuring that the puncture needle reaches the center of the hematoma accurately at once without repeated adjustment. This not only greatly shortens the surgical time but also avoids unnecessary damage to surrounding normal tissues caused by puncture, thereby reducing intraoperative bleeding.

In terms of hematoma clearance rate, the robot navigation group was significantly higher than the conventional puncture group, which is of great significance for patient prognosis. The core reason for the difference in hematoma clearance rate between the two groups is the difference in puncture accuracy. Traditional minimally invasive puncture surgery may not reach the central area of the hematoma due to insufficient puncture accuracy, and the puncture needle may only be able to drain the surrounding blood of the hematoma, making it difficult to effectively remove the coagulation block in the hematoma center, resulting in incomplete hematoma removal. At the same time, the deviation of puncture position may also cause the drainage tube side hole to not be completely placed inside the hematoma, and some side holes may be exposed to normal brain tissue areas, thereby weakening the drainage effect and further affecting the hematoma removal rate; The puncture operation assisted by robot navigation can ensure that the puncture needle accurately reaches the center of the hematoma and the drainage tube side hole can be completely placed inside the hematoma, maximizing the drainage efficiency to fully discharge the blood and clots inside the hematoma. At the same time, based on the precise puncture position, doctors can adjust the drainage speed and time more reasonably according to the specific situation of the hematoma, avoiding new injuries caused by rapid drainage, leading to a sudden drop in intracranial pressure or affecting the hematoma clearance effect due to slow drainage. A more thorough removal of hematoma can effectively reduce the pressure on surrounding brain tissue, alleviate the increase in intracranial pressure to create favorable conditions for the recovery of cerebral blood perfusion, shorten the time of cerebral ischemia and hypoxia, and thus reduce the degree of cerebral tissue damage. This also lays a solid foundation for the subsequent recovery of neurological function in patients [2].

In this study, there was no significant difference in NIHSS scores between the two groups of patients before intervention, indicating that the degree of neurological damage before treatment was basically the same and comparable between the two groups of patients; After intervention, the NIHSS score of the robot navigation group was significantly lower than that of the conventional puncture group, indicating that minimally invasive puncture drainage treatment assisted by robot navigation has a more significant role in promoting the recovery of patients' neurological function. Analyzing its mechanism, firstly, the higher hematoma clearance rate of the robot navigation group can effectively relieve the compression of hematoma on nerve tissue, improve the blood and oxygen supply of nerve tissue to provide a good recovery environment for damaged nerve cells, and reduce the number of nerve cell apoptosis. Secondly, the application of robot navigation technology reduces the damage to the surrounding normal nerve tissue during surgical operations. Traditional puncture techniques may damage the nerve fiber bundles around hematomas and cause new nerve dysfunction due to insufficient accuracy. However, precise puncture assisted by robot navigation can minimize this problem and protect normal nerve function, allowing patients to better recover their nerve function to the original state. In addition, the robot navigation group has less intraoperative bleeding, shorter surgical time, and faster postoperative recovery for patients, allowing for earlier rehabilitation training. Early rehabilitation training can activate brain compensation mechanisms, promote the remodeling of damaged neural pathways, and further improve neurological function [3,4].

In terms of complications, the overall incidence rate of the robot navigation group was significantly lower than that of the conventional puncture group, with zero incidence of intracranial rebleeding and nerve injury, and a lower incidence of infection compared to the conventional puncture group. This fully confirms the higher safety of robot navigation-assisted therapy. Intracranial rebleeding, as one of the most serious complications after hypertensive intracerebral hemorrhage surgery, often leads to a rapid deterioration of the patient's condition and even endangers their life. Traditional puncture surgery is prone to intracranial rebleeding. On the one hand, due to insufficient puncture accuracy, the puncture needle may damage the surrounding blood vessels and cause vascular rupture and bleeding. On the other hand, incomplete hematoma removal may cause residual hematoma to continue to compress the surrounding blood vessels or their decomposition products to damage the blood vessel wall, leading to new bleeding [5,6]. The precise puncture assisted by robot navigation can effectively avoid damage to blood vessels caused by puncture, and more thorough hematoma removal also reduces the adverse effects of residual hematoma on blood vessels, thereby reducing the risk of intracranial rebleeding. The occurrence of nerve injury is mainly due to accidental injury of the surrounding nerve tissue during the puncture operation. The robot navigation system can clearly display the location of nerve tissue and guide doctors to avoid these important structures, thus significantly reducing the incidence of nerve injury. The occurrence of infection is related to factors such as surgical time and sterile operation during surgery. The robot navigation group has a shorter surgical time, which can reduce the chance of bacterial contamination during the surgical process. At the same time, precise puncture can reduce tissue damage to reduce susceptibility to infection, resulting in a relatively lower incidence of infection [7,8].

5. Conclusion

In summary, the application of robot navigation assistance in minimally invasive puncture and drainage treatment for hypertensive intracerebral hemorrhage can significantly optimize surgical indicators, promote neurological function recovery, and reduce the probability of complications. It provides a safer and more efficient treatment option for hypertensive intracerebral hemorrhage patients and has important clinical promotion value. In future clinical practice, personalized adjustments can be made to navigation system parameters and puncture plans based on individual patient differences (such as hematoma type, location, underlying disease, etc.) to further improve treatment efficacy and long-term patient prognosis.

Disclosure statement

The authors declare no conflict of interest.

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