Efficacy and safety of a neurointerventional operation robotic assistance system in cerebral angiography

He Liu, Conghui Li, Shaohua Ren, Tong Li, Hongliang Zhong, Jianwen Jia, Hongchao Yang, Yi Qi, Junqiang Feng, Youxiang Li, Yang Wang

ABSTRACT

Background At present, neurointerventional surgery requires angiographers to perform operations in the digital subtraction angiography (DSA) room. Ionising radiation and chronic joint damage are still unavoidable for angiographers. Therefore, we researched and developed a neurointerventional robot-assisted system, which is operated by angiographers in an operating room outside the DSA room. We have conducted a prospective, multicentre, randomised controlled trial to evaluate the safety and efficacy of a robot-assisted system in human cerebral angiography. In the future, this research will provide a platform for the research and development of an intelligent surgical system and bring revolutionary progress in neurointerventional surgery.

Methods From December 2020 to December 2021, 260 patients were enrolled from three medical centres, who were randomly and equally divided into a robot-assisted system group and a clinical routine cerebral angiography group. The success rate of angiography, the rate of the catheter reaching the target vessel, the operation time, X-ray radiation exposure and the incidence of related adverse events were compared between the two groups.

Results A total of 257 patients completed this trial; baseline characteristics of the two groups did not differ significantly. The success rate of angiography in both the control group and the experimental group was 100%. The rate of the catheter reaching the target vessel was 99.23% and 100.00% in the control group and the experimental group respectively. For the control versus experimental groups, the angiographic operation time was 48.59±25.60 min versus 47.94±27.49 min, respectively; the X-ray radiation dose was 735.01±554.77 mGy versus 821.65±705.45 mGy, respectively; and the incidence of adverse events was 23.44% versus 22.48%, respectively. No statistical differences were present between the two groups.

Conclusion The robot-assisted surgical system is more convenient for cerebral angiography and is as safe and effective as the traditional cerebral angiography.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ At present, neurointerventional surgery requires angiographers to perform operations in the digital subtraction angiography (DSA) room. Ionising radiation and chronic joint damage are still unavoidable for angiographers. Therefore, we researched and developed a neurointerventional robot-assisted system, which is operated by angiographers in an operating room outside the DSA room.

WHAT THIS STUDY ADDS

⇒ We have conducted a prospective, multicentre, randomised controlled trial to evaluate the safety and efficacy of a robot-assisted system in human cerebral angiography. As far as we know, it is the largest clinical study of a vascular surgery assistance system involving clinical samples.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ It provides clinical experience and data for the R&D, transformation and marketing of subsequent neurointerventional therapy products and also provides a basis for the government to formulate policies for introducing relevant medical products into clinical application. In the future, this research will provide a platform for the research and development of an intelligent surgical system and bring revolutionary progress in neurointerventional surgery.

INTRODUCTION

The term ‘robot’ is derived from the Czech word ‘robota’ used in a Czech play in 1920 to mean servitude or forced labour.1 Robots were first used in clinical practice in 1985.2,3 To date, it has been used in a variety of surgical fields.4-6 In the field of surgical treatment of cerebrovascular diseases, the emergence of vascular interventional technologies has changed the way of disease treatment. Nowadays, neurointerventional therapy is widely applied, which plays an increasingly important role in the treatment of haemorrhagic and ischaemic diseases such as aneurysms and vascular malformations.

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What is already known on this topic

⇒ At present, neurointerventional surgery requires angiographers to perform operations in the digital subtraction angiography (DSA) room. Ionising radiation and chronic joint damage are still unavoidable for angiographers. Therefore, we researched and developed a neurointerventional robot-assisted system, which is operated by angiographers in an operating room outside the DSA room.

What this study adds

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How this study might affect research, practice or policy

⇒ It provides clinical experience and data for the R&D, transformation and marketing of subsequent neurointerventional therapy products and also provides a basis for the government to formulate policies for introducing relevant medical products into clinical application. In the future, this research will provide a platform for the research and development of an intelligent surgical system and bring revolutionary progress in neurointerventional surgery.

What is already known on this topic

⇒ At present, neurointerventional surgery requires angiographers to perform operations in the digital subtraction angiography (DSA) room. Ionising radiation and chronic joint damage are still unavoidable for angiographers. Therefore, we researched and developed a neurointerventional robot-assisted system, which is operated by angiographers in an operating room outside the DSA room.
damage to the doctors’ joints and ligaments. Thus, with the help of the robot-assisted system, the angiographers will not be exposed to ionising radiation in the operating room outside the digital subtraction angiography (DSA) room. They generally take a sitting position and have no need to wear personal protective equipment, so chronic damage to joints and ligaments can be avoided. Because standardised interventional manoeuvres consist of a set of forward and backward linear motion combined with rotational manoeuvres, this type of repetitive motion is exactly what the robot does best. We research and developed this interventional unit, a neurointerventional surgery assistance system, YDHB-NS01 (Yidu Hebei Robot Technology Co., Ltd., Hebei Province, China), which can provide a foundation for carrying more diversified and smarter devices in the near future. The platform can also offer possibilities for telemedicine for patients and can be used for training interventional doctors. This study is a clinical study related to transformational products. As far as we know, it is the largest clinical study of a vascular surgery assistance system involving clinical samples. This project has been strongly supported by the government for many years and has become a key research and development project of the Ministry of Science and Technology of China. At present, we only use this system to perform whole-brain angiography for clinical research. This paper reports the use of this system in a multicentre, prospective, randomised controlled clinical trial to validate its safety and efficacy in clinical application. This is because cerebral angiography covers basic operations of vascular intervention, and the experimental design is relatively simple, the risk of clinical application is low, and it is easy to commercialise such product. It provides clinical experience and data for the R&D, transformation and marketing of subsequent neurointerventional therapy products, and it also provides a basis for the government to formulate policies for introducing relevant medical products into clinical application.

METHODS AND MATERIALS
This study is a randomised, parallel, controlled, non-inferiority multicentre clinical trial. It was completed at three centres: Beijing Chaoyang Hospital affiliated to Capital Medical University, Shanxi Provincial People’s Hospital and the First Hospital of Hebei Medical University. Clinical study protocols were reviewed and approved by individual institutional review boards, and patients provided written informed consent. Through screening and evaluation, subjects who met the inclusion/exclusion criteria of the research plan were randomly divided into experimental and control groups at a 1:1 ratio. The experimental group had the minimally invasive vascular interventional surgery using the robot-assisted system, while the control group received the traditional cerebral angiography. Both treatments were performed by doctors with extensive experience in neurointerventional surgery to objectively evaluate the safety and effectiveness of the neurointerventional robotic assistance system. For details, please refer to online supplemental file 1.

Inclusion and exclusion criteria
Patients participating in this clinical trial were required to meet all of the following criteria: (1) the patient is 18–75 years old; gender is not limited; (2) the patient has cerebrovascular disease and requires interventional angiography; (3) the subject agrees to voluntarily sign the consent form. Patients who met any of the following criteria were excluded: (1) patients with severe infectious diseases such as bacteraemia and toxaemia; (2) patients with severe coagulation disorders; (3) patients with severe heart, brain, lung or other disease; (4) patients with implanted cardiac pacemakers or defibrillators or any other electronic device or metal part (This interventional robot system belongs to Class III equipment. The electromagnetic generated by it may affect the operation of cardiac pacemaker,); (5) patients with a history of epilepsy; (6) patients with arrhythmias; (7) patients who had experienced acute myocardial infarction within the past 6 months; (8) pregnant or lactating women and those planning to become pregnant within 1 year; (9) patients who had participated in any clinical trials of drugs and/or medical devices within 3 months before enrolment and (10) any patient, who after evaluated by researchers, was considered to have any other factor making them unsuitable for inclusion. The detail of experiment flowchart is shown in figure 1.

Design method
Randomisation design
A stratified block randomisation method was adopted, and SAS V.9.4 statistical software was used to generate random codes according to a 1:1 ratio of the control group to the experimental group. Eligible subjects were then randomly assigned to group according to the time of enrolment.

Blind design
This trial was a randomised, parallel, active control trial with no blinding. The operating standards adopted by the experimental group and the control group were consistent: all participating researchers received product operation training, and each centre was operated by two or more experienced neurointerventional doctors with intermediate professional titles or above. Each centre completed the same number of subjects in the experimental and control groups.

Clinical evaluation
The success rate of the angiography was used as the primary endpoint. Procedural success was defined as catheter arrival at the intended site with no complications. The incidence of clinical complications, adverse events (AEs) and performance indicators within 3 days after angiography (or, at the time of discharge, if this was <3 days) was used as the safety evaluation index. Complications include: (1) puncture related: perivascular haematoma.
puncture, vasospasm at the puncture site, vascular dissection, pseudoaneurysm, arteriovenous fistula, puncture site infection; (2) procedure related: intracranial vasospasm, atherosclerotic plaque sloughing, thrombosis, vascular injury, vascular dissection, vascular perforation, vascular rupture, vascular occlusion, pseudoaneurysm, arteriovenous fistula, haemorrhage, intracranial aneurysm or arteriovenous malformation, air embolism; (3) neurological complications: transient ischaemic attack, epilepsy, opisthotonistolus, complete amnesia, ischaemic stroke. AE include but are not limited to: metabolic and nutritional diseases, lung infections, increased blood pressure, elevated blood glucose, headache, constipation. The detail is in online supplemental table 1.

**Operation time**

As the assistance system cannot replace the doctor to puncture the femoral artery and place the arterial sheath, this procedure was done by the doctor in both groups. The so-called angiography time, thus, started from the time when the 5F angiography catheter entered the femoral artery and ended when the 5F angiography catheter was withdrawn from the femoral artery sheath after the end of the angiography.

**Criteria for discontinuation of the trial/treatment**

Subjects could withdraw from the trial for any of the following reasons. (1) Those who had allergic reactions or serious AEs and should stop the trial according to the doctor’s judgement. (2) Those whose condition deteriorated during the trial and should stop the trial according to the doctor’s judgement. (3) Those with poor compliance according to the investigator’s judgement. (4) Subjects that withdrew voluntarily. (5) Subjects unwilling or unable to continue the clinical trial for any reason that asked the investigator to withdraw from the trial. (6) Subjects that did not explicitly request to withdraw from the trial, but no longer had follow-up.

**Figure 1**  
Experiment flowchart. FAS=number of people randomly enrolled−number of people who did not use any research equipment; PPS=FAS−lost to follow-up or the patient withdraws from the study; SS=FAS−number without any safety assessment (lost to follow-up). FAS, full analysis set, PPS, per-protocol set, SS, safety analysis set.

**Operation process**

The experimental medical device was a minimally invasive vascular interventional surgery assistance system, model specification, YDHB-NS01. The patient was placed supine, the bilateral inguinal areas were disinfected, the right femoral artery was punctured and an 5F arterial sheath inserted. The 5F angiography catheter was connected to the Y valve and high-pressure water injection installed on the robotic arm and a 0.035˝ (0.89 mm) ultra-smooth guide wire inserted and fixed. The manipulator arm was fixed to the Y valve and the 5F angiography catheter sent into the arterial sheath. At this point, doctors in the experimental group left the operating room and entered the console room to perform selective angiography of the aortic arch and the superior arch artery. The single contrast dose and rated pressure of the high-pressure injector were identical to that used in the control group.

The doctor’s console in the experimental group was used for remote control of the catheter controller, guide
wire controller output catheter and guide wire delivery actions. The doctor’s console included steering handles for catheter and wire delivery control. During the operation, movements of the catheter and guide wire manipulator on the robot side are synchronised with the movements of the manipulation handle. When the handle corresponding to the catheter and the guide wire is pushed forward and backward, the catheter and the guide wire controller are likewise pushed forward and withdrawn at a fixed speed. When the handle is turned clockwise or counterclockwise, the catheter controller rotates the catheter correspondingly. The robotic body catheter and guidewire manipulator use linear advancement to drive the catheter and guidewire into or out of the blood vessel. The catheter manipulator is tightly connected with the catheter and does not undergo relative axial displacement during the operation. The guidewire manipulator adopts a repeating action, with the axial delivery operation of the guidewire performed in the manner of ‘manipulator clamping—delivery; manipulator relaxation—gripper retraction’ during the operation.

**Sample size**

The experimental group and the control group were randomly assigned in a ratio of 1:1. Taking the success rate of angiography as the main curative effect index, combined with the existing clinical evidence and the experience of clinical experts, the main curative effect was estimated to be 95%. Using a one-sided α=0.025, a power of 80% (1−β) and δ=8%, the PASS V.2020 software estimated the required sample size as 117 cases in each group. Considering a 10% dropout and exclusion, the sample size of the study was set to 130 cases in each group, for a total of 260 cases.

**Statistical analysis**

SAS V.9.4 software was used for statistical analysis. All statistical tests were one sided with α=0.05 (unless otherwise specified). P≤0.05 was considered a statistically significant difference (unless otherwise specified). All CIs are given as 95% CI. Quantitative indicators are described as number of calculated cases, mean, SD, median, minimum value (min), maximum value (max), P25 (Q1) and P75 (Q3). Classification indicators are described as the number of cases and percentages of each category. Comparison of the general conditions of the two groups was analysed using appropriate methods according to the type of indicator. Quantitative data were compared between groups using the two-sample t-test or the Wilcoxon rank sum test. Categorical data were analysed using the χ² test or the exact probability method. Ranked data were analysed by the Wilcoxon rank sum test or Cochran-Mantel-Haenszel test. Efficacy analyses were performed on a full analysis set (FAS) and on a per-protocol set (PPS) basis. All baseline demographic data analyses were performed based on the FAS, and safety assessments were performed on the Safety Analysis Set.

**RESULTS**

A total of 260 subjects were randomised into two groups, giving 130 cases in each of the experimental and control groups. In the experimental group, 128 cases were completed, while two cases (accounting for 1.53%) did not complete the trial. In the control group, 129 cases were completed, while one case (accounting for 0.77%) did not complete the trial.

**Baseline**

Summary statistics (mean±SD) for subjects in the experimental group were: age=53.83±9.97 years; height=165.95±7.73 cm; weight=70.99±10.61 kg; body mass index (BMI)=25.74±3.12 kg/m². There were 48 male (37.50%) and 80 female subjects (62.50%); 124 (96.88%) subjects of Han nationality and four subjects (3.13%) of other ethnic groups. Summary statistics for the control group were: age=54.72±10.90 years; height=165.92±7.87 cm; weight=68.66±12.15 kg; BMI=24.85±3.38 kg/m². There were 59 male subjects (45.38%), 71 female subjects (54.62%) and 130 (100.00%) Han subjects. No statistically significant differences were present in demographic data between the two groups (p>0.05), indicating the basic demographic characteristics of the two groups were comparable (table 1).

The mean±SD of systolic blood pressure in the experimental and control groups was 129.83±15.49 mm Hg and 129.55±13.84 mm Hg, respectively; the mean±SD of diastolic blood pressure in the two groups were 80.62±9.90 mm Hg and 81.53±10.05 mm Hg, respectively. Respiration mean±SD was 18.36±1.27 times/min and 18.36±1.27 times/min in the experimental and control group, respectively. The mean±SD of body temperature was 36.42±0.24°C and 36.43±0.26°C in the experimental and control group, respectively. The mean±SD of heart rate was 74.40±7.80 beats/min and 74.86±9.31 beats/min in the two groups, respectively. No significant differences in vital signs occurred between the two groups before treatment (p>0.05).

In summary, the control and experimental groups were comparable, with no differences in demographic data, baseline characteristics or vital signs before treatment.

**Main efficacy index: the success rate of angiography**

FAS analysis results

The success rate of angiography in the experimental group was 100.00% and the success rate of angiography in the control group was 100.00%; there was no significant difference in the operation success rate between the two groups. The 95% CI of the difference in success rate of angiography between the two groups was (−0.03%, 0.03%), which was not statistically significant, and, thus the experimental group was non-inferior to the control group.

In the experimental group, the catheter reached the correct position in 128 cases (100.00%). In the control group, the catheter reached the correct position in 129 of 130 cases (99.23%). In the experimental group, 128
cases (100.00%) were visualised by target angiography; in the control group, 129 cases (99.23%) were visualised by target angiography and 1 case (0.77%) was not visualised by target angiography. The 95% CI of the difference between the arrival position of the catheter and the angiographic imaging difference between the two groups was (−0.02% to 0.04%), which was not statistically significant, and it could be considered that the experimental group was non-inferior to the control group.

PPS analysis results

The control group sample size for PPS analysis was decreased due to one case dropping out when contact was lost.

The success rate of angiography in the experimental group was 100.00% and the success rate of angiography in the control group was 100.00%; success rate of the operation did not differ significantly between the two groups. The 95% CI of the difference in success rate of angiography between the two groups was (−0.03%, 0.03%), which was not statistically significant, and it could be considered that the experimental group was non-inferior to the control group.

In the experimental group, the catheter reached position in 128 cases (100.00%); in the control group, the catheter reached position in 128 cases (99.22%) and in one case (0.78%) did not reach position. In the experimental group, 128 cases (100.00%) were visualised by target angiography; in the control group, 128 cases (99.22%) were visualised by target angiography and one case (0.78%) was not visualised by target angiography. The 95% CI of the difference between the arrival position of the catheter and the angiographic imaging difference between the two groups was (−0.02% to 0.04%), which was not statistically significant, and it could be considered that the experimental group was non-inferior to the control group.

The results of PPS and FAS were consistent, and, thus, we conclude that the experimental group was non-inferior to the control group (see tables 2 and 3 for details).

Secondary efficacy index: operation time

FAS analysis results

The mean and SD of angiography operation time in the experimental group was 47.94±27.49 min; the mean and SD of angiography operation time in the control group was 48.50±25.68 min. No significant difference in angiography operation time occurred between the two groups.

PPS analysis results

The mean and SD of angiography operation time in the experimental group was 47.94±27.49 min; the mean and SD of angiography operation time in the control group was 48.50±25.68 min. No significant difference in angiography operation time occurred between the two groups.

Table 1 Baseline demographics

<table>
<thead>
<tr>
<th>Index</th>
<th>Experimental group</th>
<th>Control group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years</td>
<td>Number of cases</td>
<td>128 (0)</td>
<td>130 (0)</td>
</tr>
<tr>
<td></td>
<td>Mean±SD</td>
<td>53.82±9.97</td>
<td>54.72±10.99</td>
</tr>
<tr>
<td>Sex, n (%)</td>
<td>Number of cases</td>
<td>128 (0)</td>
<td>130 (0)</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>48 (37.50)</td>
<td>59 (45.38)</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>80 (62.50)</td>
<td>71 (54.62)</td>
</tr>
<tr>
<td>Nationality, n (%)</td>
<td>Number of cases</td>
<td>128 (0)</td>
<td>130 (0)</td>
</tr>
<tr>
<td></td>
<td>Han nationality</td>
<td>124 (96.88)</td>
<td>130 (100.0)</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>4 (3.13)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>Number of cases</td>
<td>119(9)</td>
<td>122(8)</td>
</tr>
<tr>
<td></td>
<td>Mean±SD</td>
<td>165.93±7.73</td>
<td>165.92±7.87</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>Number of cases</td>
<td>119(9)</td>
<td>123(7)</td>
</tr>
<tr>
<td></td>
<td>Mean±SD</td>
<td>70.99±10.61</td>
<td>68.66±12.15</td>
</tr>
<tr>
<td>BMI (Kg/m²)</td>
<td>Number of cases</td>
<td>119(9)</td>
<td>122(8)</td>
</tr>
<tr>
<td></td>
<td>Mean±SD</td>
<td>25.74±3.12</td>
<td>24.85±3.38</td>
</tr>
</tbody>
</table>

BMI, body mass index.
Thus, no difference in the angiography operation time occurred between the experimental group and the control group (see tables 4 and 5 for details).

**The doses of radiation from X-rays (mGy)**

The X-ray radiation dose received by subjects in the experimental group was 735.01±554.77 mGy and in the control group was 821.65±705.45 mGy. Radiation doses did not significantly differ between the two groups (see table 6 for details).

**Safety indicators**

Among the 129 subjects in the experimental group, 30 cases (43 events) had AEs, and the incidence of AEs was 23.44%; among the 129 subjects in the control group, 29 cases (47 events) had AEs, and the incidence of AEs was...
These differences were not statistically significant. There were also no significant differences in body temperature, heart rate, respiration, systolic blood pressure and diastolic blood pressure between the experimental group and the control group during and following the operation (p>0.05). There were no related complications during the operation and postoperative follow-up in the experimental group and the control group.

DISCUSSION
The assistance system for vascular intervention surgery expands and extends the doctor’s ability, in order to solve the problems and limitations of traditional vascular interventional surgery. The catheter manipulator robot body and the supporting mechanical arm are fixed on the operating bed and move synchronously with it. The catheter controller, the guide wire controller and the auxiliary support catheter are installed in the corresponding parts of the robot body. In addition, the catheter and the guide wire can independently move back and forth and rotate around the axis. The basic working mechanism of the robotic system is as follow: (1) the control device (e) is located outside the operating room; (2) the slave end operation device (a, b, c) is located on the operating room, and there is a catheter controller and guide wire controller (a), respectively, clamp and control the forward, backward and rotation of the catheter and guide wire; (3) by observing the DSA screen (d) located outside the operating room, the doctor can judge the position of the catheter and guide wire in real time, and control the forward, backward and rotation of the catheter and guide wire through the handle (e), so as to realise the surgical operation (figure 2 and online supplemental video).

In this trial, the operation success rate of both the experimental group and the control group was 100% and no intraoperative complications occurred. Thus, angiography using the assistance system is not inferior to traditional angiography in terms of safety. However, more complicated operations were not performed in this experiment. Preliminary clinical case reports have shown the feasibility of robotic-assisted systems in procedures such as stent-assisted embolisation of intracranial aneurysms and stenting of carotid atherosclerotic stenosis. In theory, precision mechanical systems have a stability and accuracy surpassing that of human beings, but there is currently insufficient high-quality data to support the conclusion that the safety performance of robot-assisted systems is not inferior to traditional doctor operations in more complex surgical procedures. To adapt to more delicate and complex operations and obtain higher safety, feedback of force and instrument displacement changes should be incorporated into the robot handle in future. This will quantify the force given by the operator to the guide wire and catheter and enhance the degree of freedom the surgeon has during the operation. If the operating doctor exceeds an alert range, the system’s warning will reduce risk during complex surgery. Using the assistance system can reduce radiation exposure. To reduce the radiation exposure of patients and staff.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Operating time analysis results (FAS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index</td>
<td>Experimental group</td>
</tr>
<tr>
<td>Operation time (min)</td>
<td></td>
</tr>
<tr>
<td>Number of cases (number of missing)</td>
<td>128 (0)</td>
</tr>
<tr>
<td>Mean±SD</td>
<td>47.94±27.49</td>
</tr>
<tr>
<td>Median</td>
<td>45.00</td>
</tr>
<tr>
<td>Q1, Q3</td>
<td>28.50, 60.50</td>
</tr>
<tr>
<td>Min, max</td>
<td>7.00, 173.00</td>
</tr>
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</table>

FAS, full analysis set.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Operating time analysis results (PPS)</th>
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<tbody>
<tr>
<td>Index</td>
<td>Experimental group</td>
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<tr>
<td>Operation time (min)</td>
<td></td>
</tr>
<tr>
<td>Number of cases (number of missing)</td>
<td>128 (0)</td>
</tr>
<tr>
<td>Mean±SD</td>
<td>47.94±27.49</td>
</tr>
<tr>
<td>Median</td>
<td>45.00</td>
</tr>
<tr>
<td>Q1, Q3</td>
<td>28.50, 60.50</td>
</tr>
<tr>
<td>Min, max</td>
<td>7.00, 173.00</td>
</tr>
</tbody>
</table>

PPS, per-protocol set.
especially operating physicians, many efforts have been made to reduce the amount of ionising radiation in DSA and protective equipment. Reducing radiation exposure of patients relies on reducing exposure (surgery) time or use of other technical means to reduce radiation. It has been reported before that the use of neurointerventional assistance systems can reduce the radiation dose of the operator by nearly 95.2% or more and that the exposure of patients was also significantly reduced. In the current clinical trial, the use of a robotic assistance system can avoid nearly 100% of radiation exposure for the operating doctor. However, due to the operation time (48.59±25.60 mins in the experimental group and 47.94±27.49 mins in the control group) and radiation exposure amounts (735.01±554.77 in the experimental group and 821.65±705.45 in the control group), there

### Table 6  The results of radiation dose analysis (SS) of the subject

<table>
<thead>
<tr>
<th>Index</th>
<th>Experimental group</th>
<th>Control group</th>
<th>Statistics</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject’s X-ray radiation dose (mGy)</td>
<td>Number of cases (number of missing)</td>
<td>124 (4)</td>
<td>124 (5)</td>
<td>t=1.08</td>
</tr>
<tr>
<td></td>
<td>Mean±SD</td>
<td>735.01±554.77</td>
<td>821.65±705.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Median</td>
<td>505.30</td>
<td>582.50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q1,Q3</td>
<td>417.50, 926.55</td>
<td>495.55, 965.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Min, max</td>
<td>233.63, 4940.56</td>
<td>216.50, 7138.93</td>
<td></td>
</tr>
</tbody>
</table>

SS, safety analysis set.

![Figure 2](https://example.com/figure2.png)  
Figure 2  The basic structure of the robot assistant system. (A) a Disposable accessories, b Operating arm, c Control cabinet, d Workstation, e Operation console. (B) Inside the solid line: the operating room. Inside the dotted line: the control device room. (C) The robot working in the operating room. (D) The neurointerventionalist was controlling the robot outside of the operating room (in the control device room).
was no statistical difference and radiation exposure to patients was not reduced. If the doctor’s proficiency in the operation of the system increases and the manoeuvrability of the assistance system improves, the radiation exposure time of the patient may be reduced.

In this study, in order to reduce the unknown risks of clinical trials and comply with ethical requirements, the doctor operating the assistance system has undergone thorough training and passed the assessment to be proficient in operating them. In addition, the joystick of the system is very flexible, allowing easy manipulation of the rotation and movement of the guidewire and catheter. The above may be the reason why there is no difference in operation time between the experimental group and the control group.

Another advantage of robots is their ability to be controlled remotely. Doctors can use this to perform remote surgical operations, making this a potential breakthrough technology for the treatment of acute stroke, especially the time-dependent mechanical thrombectomy. This could be carried out in primary hospitals, avoiding the delay past the best time for surgery caused by a need to transfer patients to another facility and especially benefiting patients in remote areas. However, this depends on the speed of data transmission across the network; the time delay must be negligible, or it will cause great danger for remote surgery. While other issues, such as equipment optimisation and strict supervision still need to be resolved, the potential of its realisation remains high.

CONCLUSION

The assistance system is easy to operate for cerebral angiography and has a success rate and operation time similar to the level of experienced doctors, indicating that it is safe and effective. At the same time, continuous improvement of the system, including additional force feedback, warning reminders to operators and multimodal image fusion, will enable more complex operations and more possibilities for the system.

Contributors

HL designed data collection tools, monitored data collection for the whole trial, wrote the statistical analysis plan, cleaned and analysed the data, and drafted and revised the paper; CL implemented the trial in Department of neurosurgery, the 1st Affiliated Hospital, Hebei Medical University, analysed the data, and drafted and revised the paper; LR designed da ta collection tools, monitored data collection for the whole trial, wrote the statistical analysis plan, and revised the draft paper; ZZ, JJ, HY, YW propose research directions, monitor and manage the progress of the whole research, designed data collection tools, monitored data collection for the whole trial, revised the paper and as the guarantor.

Funding

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Competing interests

None declared.

Patient consent for publication

Not applicable.

Ethics approval

This study involves human participants and was approved by the Ethical Committee of the 1st Affiliated Hospital of Hebei Medical University.

Supplemental material

This material is available as part of the online article.

Data availability statement

All data relevant to the study are included in the article or uploaded as supplementary information.

Open access

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REFERENCES


Program number: JQR001

Efficacy and safety of a neurointerventional operation robotic assistance system in cerebral angiography

*Name of investigational medical device:* minimally invasive vascular interventional surgical assistance system

*Model specification:* YDHB-NS01

*Management categories of investigational medical devices:*

three categories

- Class III medical devices subject to clinical trial approval: Yes ☐ No ☑
- Similar products in China: Yes ☐ None ☑

*Scheme version number and date:* V3 0/20210915

*Clinical trial institution:* Beijing Chaoyang Hospital affiliated to Capital Medical University

*Coordinator:* Wang Yang

*Sponsor:* Yidu Hebei Robot Technology Co., Ltd

*Agent:* Feiwei (Shanghai) Pharmaceutical Technology Co., Ltd
Sponsor information

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(2) Address of the sponsor: 1st floor, Block B, Building 2, Baoding Zhongguancun Innovation Base, No. 369 Huiyang Street, Baoding City
(3) Contact information of the sponsor: Chen Yang 0312-5905155
(4) Relevant qualification documents of the sponsor: see Annex
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   Name of agent: FINWAY (Shanghai) Pharmaceutical Technology Co., Ltd
   Address: Room 1006, Yalong Dongshuo Space, No. 7, Lane 200, Yunxin Road, Jing'an District, Shanghai
   Contact: 13761801901
   Relevant qualifications: see annex

A list of all clinical trial institutions and investigators

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Purpose and content of clinical trials

objective

This study is a pre-marketing clinical trial of minimally invasive vascular interventional surgical assistance system, which provides clinical data for the formal application of the product in China by evaluating the effectiveness and safety of minimally invasive vascular interventional surgical auxiliary system in cerebrovascular interventional angiography Basis.

current

1. Clinical study evaluation endpoints

1. Main evaluation indicators
   success rate.

2. Secondary evaluation indicators
   Operation time.

2. Effectiveness evaluation methods

1. Validity:
   Definition of successful angiography: The catheter arrives at the location to enable successful imaging of the target vessel.

   Definition of operating time: the time from the entry of the catheter into the body to the withdrawal of the catheter.

2. Performance indicators:

   Operator evaluation: whether the operation station is stable, whether the catheter and guide wire delivery are smooth, whether the support robotic arm is flexible, whether the controller is flexible, and whether the equipment fails.

3. Safety evaluation methods

   1) The amount of radiation from the X-rays of the patient subject.

   2) Incidence rate of complications: intraoperative and 3 days after surgery (if the discharge time is ahead, that is, at the time of discharge). Observe and record the occurrence and timing of complications in patients who were followed up with the trial.

      Complications include:

      1. Puncture-related: perivascular hematoma puncture, vasospasm at the puncture site, vascular
dissection, pseudoaneurysm, arteriovenous fistula, puncture site infection.


3. Neurological complications: transient ischemic attack, epilepsy, opisthotonistolus, complete amnesia, ischemic stroke.


3) Adverse events

Adverse events include but are not limited to: Major Adverse Cardiovascular Events (MACE): defined as vascular dissection, vascular avulsion, vascular rupture, new cerebral embolism, bloodstream infection, and death. Cortical blindness, broken guidewire, kink, severe allergy to contrast media, lung infection, renal failure, impaired consciousness, death, malfunction of robot operation.

Background

According to the World Health Organization, about 17.9 million people died of cardiovascular and cerebrovascular diseases in 2016, accounting for 31% of the total deaths, of which 85% died of heart disease and stroke [1]. According to the "China Cardiovascular Disease Report 2017", there are about 290 million patients with cardiovascular and cerebrovascular diseases in China, including 270 million patients with hypertension, 13 million patients with stroke and 110 million patients with coronary heart disease [2]. Cardiovascular and cerebrovascular diseases accounted for 45.01% of the deaths of residents' diseases, 45.01% in rural areas and 42.61% in urban areas, ranking first among various diseases, higher than tumors and other diseases [2-3].

At present, the treatment of cardiovascular and cerebrovascular diseases is divided into drug therapy and surgical treatment, and there are usually two methods of surgical treatment, one is traditional open surgery, and the other is minimally invasive vascular interventional surgery [4]. Traditional open surgery mainly uses open cavities or craniotomy to expose the location of the lesion and then treat. This method has great tissue damage to the patient, a large amount of bleeding, slow postoperative recovery, high risk of surgery, and the patient needs to bear great pain [5,6]. Compared
with traditional open surgery, minimally invasive interventional surgery makes an incision at the blood vessel, and under the guidance of medical imaging, special medical catheters and guidewires are inserted from the incision and pushed to the lesion location, and then other medical devices are used to treat the lesion location, such as the dissolution of thrombus, the placement of vascular stents, etc.\cite{5,7}. The use of interventional surgery for treatment has the advantages of less trauma, less bleeding, fast postoperative recovery, reduced pain, and fewer complications, and has been widely used\cite{5}. During interventional procedures performed on the spot, doctors need to use X-rays to complete the entire operation. To avoid the harm caused by radiation, doctors often wear bulky lead clothing. Due to the limited protective area of lead clothing and the need for doctors to work under radiation for a long time, doctors have an increased risk of cancer\cite{8}. During the operation that lasts for several hours, doctors need to wear lead clothing weighing up to 10 kg, which is very easy to cause fatigue and easily induce chronic diseases such as cervical spondylosis and lumbar spondylosis\cite{9}. The specialized vascular interventional robot technology provides an effective solution to the above problems, which can promote the further development and wide application of traditional vascular interventional technology.

The minimally invasive vascular interventional surgery assistance system aims to combine robot technology with traditional vascular interventional technology, and use the rapidity, high stability, high positioning accuracy, high computing power and rich sensing information of robots to realize the expansion and extension of doctors’ capabilities and solve the problems and limitations of traditional vascular interventional surgery. Most vascular interventional surgery robots adopt master-slave control mode, which is composed of the doctor-to-master-end console, slave-end robot, image interaction system and control system. During robot-assisted surgery, the doctor adopts a sitting posture in front of the console, controls the specially designed operation handle or button, realizes the control of the slave robot, and the slave robot realizes the pushing, pulling and twisting operation of the catheter, so as to reproduce the doctor's surgical operation, and at the same time detects the operating force of the catheter from the internal sensing system of the end robot and sends it to the main console in real time, and the feedback force generation device of the main end console provides the doctor with tactile feedback of the operating force of the catheter. During the operation, the doctor observes the surgical status of the catheter in the human vascular lumen through the image interaction system (DSA, MRI and other medical images), and makes surgical operation decisions based on the tactile feedback of the hand, so as to complete the vascular interventional operation.
This product has passed the test of Beijing Medical Device Inspection Institute of the State Medical Products Administration, and the performance indicators have met the standard requirements, and the test results are qualified.

This product has been tested on animals to verify its safety and efficacy in animals. According to the relevant content of the “Good Clinical Trial Practice for Medical Devices” (Order No. 25 of the State Food and Drug Administration), clinical trials were conducted to verify their clinical safety and effectiveness.

**Product characteristics, structural composition, working principle, mechanism of action and test range**

1. **Product features**

The main features of the minimally invasive vascular interventional surgical assistance system are as follows:

(1) The system adopts master-slave operation mode. The system slave operator is set on the patient side and the main end operator is set on the doctor side, and the master-slave control can use both wired communication set in the same city and network communication mode set up in different places. When wired communication is used, the main operator (doctor's side) is located in the close isolation area outside the operating room, freeing the doctor from the radiation working environment. When using network communication, the main manipulator (doctor's side) can be set in a remote place far away from the patient (operating room), which can effectively extend the doctor's skills, expand the coverage of surgery, and reduce the geographical dependence of complex surgery on experts.

(2) The system slave operator can provide at least 2 degrees of freedom catheter operation movement. In the process of vascular interventional surgery, the movement of the catheter relative to the vascular incision has forward or backward axial movement, and the rotational movement around the catheter itself, and the operation of the catheter needs to provide at least 2 degrees of freedom under the premise of meeting the requirements of surgical operation. In most studies, robotic systems typically provide 2 degrees of freedom operation because the catheter has only linear and rotational motion relative to the blood vessel. In some studies, the catheter was modified to increase the control of the catheter head rotation, improve the operability of the catheter, and enhance the catheter's ability to

6
cross vascular branches. Because this method increases the size of the catheter to a certain extent, it is generally only suitable for cardiac surgery.

(3) The design form of the main end operator of the system is diversified. The function of the master operator of the system is to collect the operation movements of the doctor's hand and transmit the signal to the slave operator to control the catheter. According to the difference in the configuration of the main end operator and the slave end manipulator, it is divided into homogeneous and heterogeneous type. The main end operator using the homogeneous design method, its structure and motion form are the same as the slave operator, the advantage of this design method is that the control of the master and slave system is simple and convenient. The main end operator adopts heterogeneous operation mode, which designs a special operation handle according to the specific surgical operation requirements, such as the different operation methods of cerebrovascular interventional surgery and abdominal interventional surgery, which is convenient for doctors to operate. In heterogeneous master-side operators, in order to increase the comfort of the doctor's operation, redundant degrees of freedom are usually set, so the degrees of freedom of the master-side operator are often greater than those of the slave-end operator.

(4) The system adopts different signal feedback methods to assist doctors in surgical operations. There are two main kinds of motion signals: position signal and collision signal, the former reflects the running posture of the catheter guidewire in the blood vessel, and the latter characterizes the collision relationship between the catheter guidewire and the blood vessel wall. At present, the minimally invasive vascular interventional surgery auxiliary system adopts signal feedback methods, including visual feedback and force feedback. However, most studies used visual feedback to assist physicians, and some introduced force feedback. The combination of visual feedback and force feedback can reproduce the motion information of the catheter guidewire more comprehensively and increase the safety of surgery.

2. Product structure composition, working principle, mechanism of action

1) Structural composition

The minimally invasive vascular interventional surgical assistance system consists of the following components:

- Doctor console
Working principle and mechanism of action

This system is used to assist doctors to complete catheter and guidewire delivery operations in vascular interventional surgery. The operator uses the doctor's console and computer workstation to complete the robot action control. The robot body and support robotic arm are fixed on the operating table and move together with the operating table, and the catheter controller, guide wire controller and auxiliary support tube are installed in the corresponding card slots of the robot body, and the delivery operation of the catheter and guide wire is carried out according to the operation instructions.

The catheter manipulator and guide wire manipulator can realize the independent back and forth movement of the conduit and guide wire and rotate around the self-axis.

The doctor's console is used for remote control catheter controller, guidewire controller, output catheter, and guidewire delivery action. The doctor's console includes controls for catheter and guidewire delivery control. During the operation, the catheter and guidewire manipulator on the robot side are synchronized with the controller action. When the handle corresponding to the catheter operator pushes forward and pushes back, the catheter controller pushes forward and withdraws the catheter at a fixed speed; When the handle is twisted clockwise or counterclockwise, the catheter controller synchronizes the rotation of the catheter. When the handle corresponding to the guide wire operator pushes forward and backward, the guide wire controller pushes forward and retreats the guide wire at a fixed speed; When the handle is twisted clockwise or counterclockwise, the guidewire controller synchronizes the rotation of the guidewire. The robotic body catheter and guidewire manipulator use a linear propulsion method to drive the catheter and guidewire into or out of the blood vessel. The catheter manipulator remains tightly attached to the catheter and does not undergo axial relative displacement during the procedure. The guidewire manipulator adopts a reciprocating delivery operation, and the axial delivery operation of the guidewire is carried out by "manipulator clamping-delivery-manipulator relaxation-gripper retraction" during the operation.

Scope of the research
This study is a pre-marketing clinical trial of minimally invasive vascular interventional surgical assistance system, which evaluates the safety and efficacy of minimally invasive vascular interventional surgical auxiliary system in cerebrovascular interventional angiography by comparing it with conventional cerebrovascular interventional angiography and provides a clinical basis for the formal application of the product in China.

Indications and contraindications of the product, possible complications and precautions

1. **Indications**

   Cerebrovascular lesions or conditions suspected to be cerebrovascular related and requiring cerebral angiography, including, but not limited to: intracranial aneurysm, cerebrovascular malformations, cerebrovascular stenosis, cerebral arteriovenous fistula.

2. **Contraindications**

   The surface material of this product is ABS plastic, which is sensitive to the material of the surface parts of this product.

3. **Possible complications and precautions**

   Including but not limited to: vascular dissection, vascular avulsion, vascular rupture, new cerebral embolism, blood infection and death.

4. **Precautions and warnings**

   4.1 **warn**

   - Do not disassemble or modify all parts and systems of this instrument by yourself.
   - This product should only be operated by a professional technician who is familiar with interventional surgery and trained in the use of this robotic system.
   - Please use this product for surgical operation with fluoroscopy display.
   - When using this product, please choose the guide tube and guide wire that are suitable for the model.
   - The non-disposable part of this product is not sterile storage, and the instrument needs to be cleaned and disinfected with alcohol cotton before each use.
When using this product, please try to avoid strong electromagnetic field interference. The use of mobile phones or mobile RF communication devices in the vicinity of this product may interfere with the normal operation of the equipment.

4.2 Precautions

- This product must be trained before use and qualified before surgical operation.
- The catheter manipulator and guide wire manipulator in this product should use the type of instrument identified at the time of purchase, and do not use non-suitable type instruments.
- As shown in Appendix B, please follow the electromagnetic compatibility instructions for this product.
- Do not use this product outside the operating room.
- This product should be cleaned after each use, as detailed in the training manual.
- This product should be routinely maintained after 100 surgical procedures.
- If any component of the system still does not function after you have tried all the recommended troubleshooting methods, contact your product provider immediately.
- Do not discard this product at will, contact the equipment manufacturer for recycling.
- If you want to obtain the paper random file of this device again, please call the after-sales service and verify the user information and obtain the document by email.

Overall design

1. experimental design

1) Purpose of the test

This study is a pre-marketing clinical trial of minimally invasive vascular interventional surgical assistance system, which evaluates the effectiveness and safety of minimally invasive vascular interventional surgical assistance system in cerebrovascular interventional angiography by comparing it with conventional cerebrovascular interventional angiography to provide a clinical basis for the formal application of the product in China.

2) Choice of test method and its rationale

This was a randomized, parallel, controlled, non-inferior multicenter clinical study. Conventional cerebrovascular interventional angiography was used as a positive control. The success rate of imaging
was used as the primary endpoint index; The incidence of clinical complications, adverse events and performance indicators 3 days after contrast surgery (if the discharge time is before, that is, at the time of discharge) were used as safety evaluation indicators. To evaluate the efficacy and safety of the test group.

3) Measures to reduce and avoid bias

Due to the characteristics of the medical device itself, it is difficult to achieve double blinding, so bias can only be controlled from the following aspects

1. The operation standards used by the experimental group and the control group were the same: the participants in the trial were required to receive product operation training, each center was operated by two or more doctors with more than intermediate titles, and each center was required to complete the same number of experimental and control subjects.

2. Loss to follow-up: Take corresponding measures in the study, record the details of the subjects, and try to obtain the cooperation of the study subjects to obtain the highest possible response rate, reduce the non-response rate, loss to follow-up and dropout in the trial study, etc.

3. Randomization: The randomization method was used to control the enrollment bias, scraping the silver area covered by the random card in the order of patient enrollment, and the subjects were divided into groups and treated accordingly according to the prompt information on the random card.

4. Main index evaluation: Contrast imaging data are evaluated by third-party experts.

4) Experimental medical devices and control medical devices

4.1 Comparison of experimental medical devices with control medical devices

Investigational medical device: minimally invasive vascular interventional surgical assistance system

Model specification: YDHB-NS01

Manufacturer: Yidu Hebei Robot Technology Co., Ltd

Control medical devices: select conventional cerebral vascular interventional contrast in clinical practice

4.2 Instrument preservation
Operating conditions

- Room temperature: 10 °C to 40 °C
- Relative humidity: 30% to 75%
- Atmospheric pressure: 700 to 1060 hPa

Transportation and storage conditions

- Current room temperature: -20 °C to +60 °C
- Relative humidity: 10% to 90%
- Atmospheric pressure: 500 to 1060 hPa

5) Subject selection

1) Inclusion criteria

- Patients are between 18-7 and 5 years old, regardless of gender.
- cerebrovascular patients requiring interventional angiography.
- Participants voluntarily signed informed consent.

2) Exclusion criteria

- Severe infectious diseases, severe coagulation dysfunction, serious heart, brain, lung and other diseases.
- Those who are allergic to control contrast agents.
- Severe hepatic and renal disease.
- Pregnant and lactating women and those planning to become pregnant within one year.
- Those who have participated in clinical trials of any drug and/or medical device within 3 months prior to enrollment.
- The investigators believe that there are any other factors that are not suitable for inclusion or affect participants' participation in the study.

3) Dropout criteria:

Dropout cases refer to cases that have signed informed consent and been screened into the trial, but for some reason have not completed the entire process of clinical trials. Cases of exfoliation should be included in FAS analysis. When the patient falls out, the investigator must fill in the reason for the dropout in the eCRF form and complete as many evaluation items as possible. Cases of exfoliation due
to adverse events must be recorded in the CRF and should be included in the adverse event evaluation. Patients who shed out cannot be replaced. Common causes of shedding are:

- loss to follow-up.
- Due to adverse events, especially serious adverse events, subjects, principal investigators, ethics committees, supervisors or/and heads of clinical pharmacology bases, national or local drug administrations in charge consider terminating the study from an ethical point of view.
- Selected subjects went against the trial protocol.

4) Exit Criteria

- Those who have allergic reactions or serious adverse events and should stop the test according to the doctor's judgment.
- Those whose condition deteriorates during the test and should stop the test according to the doctor's judgment.
- Investigators judged participants with poor adherence.
- Participants withdrew on their own.
- For whatever reason, the subject is unwilling or unable to continue the clinical trial and terminates the trial by requesting the investigator to withdraw from the trial.
- Participants were no longer accepted for follow-up although they did not explicitly withdraw from the trial.

5) Suspension criteria

- If a serious safety incident occurs during the test, the test should be stopped in time;
- If a major error is found in the clinical trial protocol during the trial, or although the plan can be implemented, there is a serious deviation in the implementation, and it is difficult to evaluate the efficacy of the product, the trial should be discontinued;
- If the product is found to have poor therapeutic effect or device defects in the test and has no clinical value, the test should be discontinued;
- The sponsor requests that the test be suspended;
- The administrative department revoked the test.

6) Time of enrollment, expected overall duration of clinical trials and reasons for their determination

This clinical trial is planned to be carried out in 6 research units of Beijing Chaoyang Hospital affiliated to Capital Medical University, Shanxi Provincial People's Hospital, the First Affiliated
Hospital of Zhengzhou University, Yangtze River Shipping General Hospital, the First Hospital of Hebei Medical University, and the Affiliated Hospital of Hebei University, and the clinical trial enrollment time is expected to be about 2 months, and time is also required for ethical meetings, data collation and statistics, and writing clinical trial summary reports, so the overall time of clinical trials is about 8 months.

7) The expected duration of participation for each subject

Each participant completed the trial 3 days after contrast (i.e. at discharge if the discharge time was ahead), so the duration of each participant's expected participation in this clinical trial is approximately 1 week.

8) Number of subjects required for clinical trials

In this trial, 260 subjects (130 in the experimental group and 130 in the control group) will be screened, and the enrollment will be completed by 6 hospitals: Beijing Chaoyang Hospital Affiliated to Capital Medical University, Shanxi Provincial People's Hospital, The First Affiliated Hospital of Zhengzhou University, Yangtze River Shipping General Hospital, First Hospital of Hebei Medical University, and Affiliated Hospital of Hebei University.

6) Effectiveness evaluation method:

6.1 Validity:

Definition of successful angiography: The catheter arrives at the location to enable successful imaging of the target vessel.

Definition of operating time: the time from the entry of the catheter into the body to the withdrawal of the catheter.

6.2 Performance indicators:

Operator evaluation: whether the operation station is stable, whether the catheter and guide wire delivery are smooth, whether the support robotic arm is flexible, whether the controller is flexible, and whether the equipment fails.

7) Safety evaluation method

7.1 The amount of radiation on X-rays of the patient subject.

7.2 Incidence of complications: intraoperative and 3 days after surgery (if the discharge time is ahead, that is, at the time of discharge). Observe and record the occurrence and timing of complications in
patients who were followed up with the trial.

Complications include:

- Puncture-related: perivascular hematoma puncture, vasospasm at the puncture site, vascular dissection, pseudoaneurysm, arteriovenous fistula, puncture site infection;
- Procedure-related: intracranial vasospasm, atherosclerotic plaque sloughing, thrombosis, vascular injury, vascular dissection, vascular perforation, vascular rupture, vascular occlusion, pseudoaneurysm, arteriovenous fistula, hemorrhage, intracranial aneurysm or arteriovenous malformation, air embolism;
- Neurological complications: transient ischemic attack, epilepsy, opisthotonistolus, complete amnesia, ischemic stroke;
- Contrast agent-related: allergy, nausea, vomiting, cerebral edema;

7.3 Adverse events

Adverse events include but are not limited to: Major cardiovascular adverse events (MACE): defined as vascular dissection, vascular avulsion, vascular rupture, new cerebral embolism, bloodstream infection, and death. Cortical blindness, broken guidewire, kink, severe allergy to contrast media, lung infection, renal failure, impaired consciousness, death, malfunction of robot operation.

8) Clinical study evaluation endpoints

8.1 Main evaluation indicators:

- Success rate.

8.2 Secondary evaluation indicators:

- Operation time.

9) Demographic and baseline indicators

- Demographic characteristics: record the age, sex, height, and weight of each subject.
- Vital signs: record body temperature, heart rate, blood pressure, breathing.

2. Process

(1) Experiment flowchart
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⁰ Pregnancy test: performed during the screening period for women of gestational age.
¹ Blood count: hemoglobin (HGB), red blood cell count (RBC), platelet count (PLT), white blood cell count (WBC).
² Coagulation function: prothrombin time (PT), fibrinogen (FIB), activated partial thromboplastin time (APTT), thrombin time (TT).
³ Liver function: alanine aminotransferase (ALT), aspartate aminotransferase (AST), total bilirubin (TBIL), alkaline phosphatase (ALP), glutamyltransferase (GGT), renal function: blood urea (UREA), blood creatinine (CR).

The above laboratory tests can be accepted within one week before screening.
Statistics

The statistical analysis will be processed using SAS 9.4 or later statistical analysis software, all statistical tests will use a two-sided test, and a P-value less than or equal to 0.05 will be considered statistically significant for the difference tested. (Unless otherwise stated).

The description of the quantitative indicator will calculate the number of cases, mean, standard deviation, median, minimum, maximum. The classification indicators are described using the number and percentage of each category.

For the comparison of the general conditions of the two groups, the group-based t-test or Wilcoxon rank sum test was used for the comparison of quantitative indicators, the chi-square test or exact probability method (if the chi-square test was not applicable) was used for classification indicators, and the Wilcoxon rank sum test or CMH test was used for grade data.

Data management

In this study, EDC was used for the collection and management of research data, and the system was provided by Gemast (Beijing) Information Technology Co., Ltd. The system is a computer network-based data collection platform, for clinical trial data collection, data transmission and data management, the system has timely data entry, real-time data challenge, data audit track, data verification, data verification, electronic signature, data locking, data storage and export and other functions, support internationally recognized data standards (such as CDISC standards). The application of this system ensures the quality of clinical trial data and its true integrity. The entire data management process is implemented in accordance with national laws and regulations and relevant data management SOPs. The main processes of data management are listed below, and other details are described in the Data Management Plan (DMP). The DMP is written by the Data Manager (DM) as a guiding document for data management, approved by the sponsor, and the data management work will be carried out according to the time, content and method defined by the DMP.

Data management workflow diagram
Feasibility analysis

1. Analysis of the likelihood of success

This product has passed the State Food and Drug Administration Beijing Medical Device Inspection Institute testing, all performance indicators have met the standard requirements, and through animal tests to verify the safety of the product in animals to reduce the risk in clinical trials.

Subjects are selected by experienced physicians in strict accordance with clinical trial protocols and a thorough assessment of their condition.

2. Analysis of the likelihood of failure

If the conclusion based on the statistical results is that the complications of the experimental group are higher than those in the control group, or serious adverse reactions occur, it means that the safety of this product is poor, and it is not suitable for clinical use. The efficacy of the experimental group is worse than that of the control group, and it is statistically significant, indicating that the efficacy of this product is not accurate, and the efficacy remains to be evaluated by other trials, and it is not suitable for clinical practice.
Quality control of clinical trials

During a clinical trial, it is important to ensure that appropriate quality control measures are in place throughout the clinical trial process. Take the following specific quality control measures:

1. Standard Operating Procedure (SOP) training
   Conduct unified SOP training for all researchers, be familiar with the specific implementation rules and operating procedures of clinical trial protocols and standardize recording methods and judgment standards. During the trial process, researchers must carefully implement the clinical plan, and the factors and indicators that have an important impact on the test results (including inclusion criteria, exclusion criteria, treatment plan, primary efficacy indicators, secondary efficacy indicators, safety indicators, dropout rate, etc.) should be controlled in key areas, and the contents of the case report form should be truthfully, carefully and carefully recorded according to the requirements of the case report form when filling in the case report form to ensure that the content of the case report form is complete, true and reliable.

2. Clinical monitoring
   Establish independent clinical monitors, who will formulate monitoring plans, lists and question forms, and regularly conduct on-site monitoring visits to clinical trial institutions according to the progress of enrollment to ensure that all contents of the research protocol are strictly observed and the correct and complete filling in of research materials. The contents of the audit include:
   - Check and trace all trial data on a case-by-case basis, check the completeness, authenticity and timeliness of the data records in the case report form, and track and verify the report of adverse events (AE);
   - All factors and indicators that have an important impact on the trial results (including inclusion criteria, exclusion criteria, treatment regimens, primary evaluation endpoints, secondary evaluation endpoints, safety indicators, dropout rate, etc.) should be verified and confirmed on site;
   - The clinical monitor must provide corresponding monitoring records and reports for each monitoring and submit them to the investigator;
   - For problems found in the audit, a question form must be drawn up and submitted to the researcher for verification and confirmation before making changes.
Ethical and informed consent for clinical trials

1. Ethics

It is the investigator's responsibility to provide the ethics committee with copies of the clinical trial protocol, detailed patient information page, and informed consent form to obtain independent approval documents for the conduct of the clinical trial.

Approval documents from the ethics committee must be obtained before the start of the clinical trial. The approval document of the ethics committee must be sent to the investigator in writing, with the list of members attending the meeting, professional information and signatures, and then the researcher will provide a copy of the approval document to the sponsor.

During clinical trials, any issues related to the safety of clinical trials, such as changes to clinical trial protocols or patient information pages, and serious adverse events in clinical trials, must be reported to the ethics committee in a timely manner. The end or early termination of a clinical trial must also be reported to the ethics committee.

2. Approval of test protocols

The design, conduct and reporting of this trial are in accordance with the Good Clinical Practice for Medical Devices, the Declaration of Helsinki (2013), and the relevant regulations and ethics committee opinions of the National Medical Products Administration (NMPA).

Before the trial begins, the investigator/research unit should obtain written approval from the ethics committee on the trial protocol, informed consent form, case report form, and other written information to be provided to the subject. During the trial, if there are any new revisions to the trial protocol, informed consent, etc., they should be approved or filed in writing by an independent ethics committee again.

3. The informed consent process and the text of the informed consent form

The investigator or his/her designated representative will be responsible for informing each subject of the research background, characteristics of the test medical device, the test protocol, and the benefits and risks of participating in the trial, and shall obtain written informed consent signed by the subject or his/her legal representative and the study physician before the subject enters the trial (prior to screening examination). The procedure specified in the programme can only be commenced if a signed
informed consent has been obtained.

Investigators will be provided with a sample informed consent form that is individually applicable to the study and reviewed by the ethics committee in accordance with GCP and regulatory requirements. The final informed consent text should contain the following: the purpose of the trial, the procedure of the test, the subject's obligations, the foreseeable benefits of participation in the trial, and the foreseeable risks and inconveniences; treatment and appropriate compensation available to subjects in the event of trial-related damages; Access to trial data and confidentiality of subject information, etc.

The informed consent form is described in a language that the subject can read. Participants and their representatives performing the informed consent process must sign and date the informed consent form. The original informed consent form should be retained by the investigator and the subject with one copy each. If there is important new information involving investigational medical devices, the informed consent form must be amended in writing, sent to the ethics committee for approval, and the subject's consent must be obtained again.

Women of childbearing age should be informed that they may have unknown risks to the fetus if they become pregnant during the study; If they wish to participate in this study, contraceptive requirements should be observed during the study; If participants are suspected of not complying with these contraceptive requirements, they cannot participate in this study.

The process of obtaining informed consent should be documented in the subject's original documentation.

**Regulations for reporting adverse events and device defects**

**1. Definition of adverse events**

Adverse events are adverse medical events that occur during clinical trials, whether or not device-related.

Adverse events included the following:

- All suspected adverse device effects;
- the presence of obvious non-related disorders, i.e., symptoms or diseases that were not present at the time of study entry;
- The deterioration of a pre-existing condition, that is, the simultaneous appearance of some
symptoms or diseases. Pre-existing conditions mean that some disease or symptom was present before the study began, and there is an original record on the medical history/physical examination record prior to treatment;

- accidental injuries or accidents;
- Any improper and unanticipated event for a medical device is an undesirable device effect, i.e., it is related to the use of the investigational product. Any adverse events caused by improper instructions for the use of the device, as well as any adverse events due to the user's error, are included in this definition.

2. Criteria for determining the severity of adverse events

- mild: perceptible signs or symptoms that do not require discontinuation of the device and special treatment;
- moderate: symptoms and signs are tolerable, require special treatment, do not interfere with daily life;
- Severe: symptoms and signs are intolerable, requiring discontinuation of the device and special treatment, affecting daily life.

Note: Adverse event severity is used to describe the intensity of the event, not necessarily the adverse event.

3. Criteria for judging the causal relationship between adverse events and medical devices

- Affirmatively related: the use of instruments and the timing of reaction occurrence are reasonable; After stopping the use of the device, the reaction stops, or rapidly relieves or improves; With reuse, the reaction reproduces and may be significantly aggravated; At the same time, there is documentary evidence; and have ruled out the influence of other confounding factors such as the original disease;
- It is likely to be related: no history of repeated use of the device, Yu Tong "definite", or although there is a combination of other devices or drugs, the possibility of a reaction caused by the combination of other devices or drugs can be basically excluded;
- May be related: the use of instruments is closely related to the time of reaction, and is supported by literature; However, more than one device or drug that causes adverse reactions, or the progression factors of the underlying disease cannot be excluded;
- May not be related: adverse reactions are not closely correlated with the time of use of the
device, the reaction manifestations are not consistent with the known adverse reactions of the device, and the development of the original disease may also have similar clinical manifestations;

- Unrelated: The occurrence of the reaction is not significantly related to the chronological order of device use; inconsistent with the type of adverse reactions of the device; The patient's clinical state or other causes may also explain the reaction, and the response is reduced or eliminated after clinical symptoms or other causes are excluded.

4. Outcome determination of adverse events

Adverse events outcomes include:

- Death: leading to the end of life (the cause and time of death must be collected);
- Unhealed/not relieved: AE has not improved/recovered after treatment;
- Recovery: After treatment of AE, the symptoms completely disappeared without sequelae;
- Sequelae: After treatment of AE, the symptoms have disappeared but there are sequelae (the name or manifestation of the sequelae should be indicated when recording);
- Remission: AE improves symptoms with treatment.

5. Serious adverse events

Serious adverse events are those that occur during clinical trials that cause death or serious deterioration of health status, including fatal illness or injury, permanent defects in body structure or function, the need for hospitalization or prolonged hospitalization, or the need for medical or surgical intervention to avoid permanent defects in body structure or body functions; Events that lead to fetal distress, fetal death, or congenital anomalies or birth defects.

6. Reporting procedures, contact information

- In order to ensure the safety of subjects, any serious adverse event that occurs between the subject's signing of the informed consent form and the end of the study, whether or not related to the investigational medical device, must be reported to the company within 24 hours of becoming aware of its occurrence;
- For serious adverse events, investigators follow up and within 24 hours of obtaining follow-up information, the recurrence, complication or progression of the original serious adverse event must be reported as a follow-up event to the original event. Serious adverse
events considered to be completely unrelated to previously reported serious adverse events should be reported separately as a new serious adverse event;

- Investigators should collect all information of subjects with serious adverse events, fill in the serious adverse event report form, determine the correlation between SAE and the study device, sign, and fax the SAE report to the company within 24 hours. After receiving the SAE report, the company will report to the Ethics Committee of the Center, the State Medical Products Administration, the Medical Device Supervision Department of the Hebei Provincial Drug Administration, and the Health and Family Planning Commission of Hebei Province by telephone or fax within the working days of the same day.

In addition to the above situation, serious adverse events that occur during the test of the subject, regardless of whether it is related to the research device, the investigator should immediately take appropriate treatment measures for the subject to ensure the safety of the subject.

The original serious adverse event report form and fax acknowledgement must be kept at the study site along with the original record form.

7. **Equipment defects**

- If the investigator or physician finds that the device has design defects before use, the trial should be stopped immediately and notify the clinical trial office and the ethics committee of the clinical institution within 24 hours, and notify the sponsor within 48 hours, and the sponsor and the investigator should re-conduct the risk assessment of the product according to the defect content, and if necessary, re-conduct the pre-clinical trial research analysis in accordance with the Administrative Measures for the Registration of Medical Devices (Order No. 4 of the State Food and Drug Administration). Clinical trials can not be resumed until the defects have been re-evaluated to eliminate them, and ethical approval should be re-conducted before the trial;

- If the device is found to be defective and causes adverse events after use, it should be handled in accordance with the requirements in 1 above;

- If the sponsor finds defects in the device during the trial, it shall notify the test institution, ethics institution and researcher within two hours after the discovery, and at the same time terminate the clinical trial of the device, and declare it in writing to the Food and Drug
Administration on record within 48 hours; If there are no adverse events during the observation period, the patient should continue to follow up and observe in accordance with the requirements of the plan, and if necessary, the follow-up observation period should be extended until it is confirmed that the defective device will not cause adverse events to the patient, and all medical expenses for extending the follow-up period shall be borne by the organizer, and if adverse events occur, they should be handled in accordance with the requirements of "(3) reporting procedures and contact information";

- If the investigator finds that the device is defective during the trial, he should immediately stop the trial and notify the office of the clinical trial institution and the clinical trial within 2 hours. The institutional ethics committee also notifies other research units and notifies the sponsor within 24 hours, the sponsor shall declare in writing to the registered drug administration within 48 hours, if there are no adverse events during the observation period, the patient should continue to follow up and observe in accordance with the requirements of the program, and if necessary, the follow-up observation period should be extended until it is confirmed that the defective device will not cause adverse events to the patient, and all medical expenses for extending the follow-up period shall be borne by the organizer, and if adverse events occur, they should be in accordance with "Reporting procedures, contact information" requirements.

Reference


Stroke and Nervous Diseases, Dec 2019, Vol. 26, No. 6


Supplementary Table 1. Adverse events

<table>
<thead>
<tr>
<th>Term</th>
<th>Experimental group (N=128)</th>
<th>Control group (N=129)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Subjects</td>
</tr>
<tr>
<td>Total number of adverse events</td>
<td>43</td>
<td>30</td>
</tr>
<tr>
<td>Metabolic and nutritional diseases</td>
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<td>3</td>
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<tr>
<td>Hypoproteinemia</td>
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<tr>
<td>Hypokalemia</td>
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<tr>
<td>Hyperlipidemia</td>
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<tr>
<td>Ear and labyrinth diseases</td>
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<td>2</td>
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<tr>
<td>Vertigo</td>
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<td>1</td>
</tr>
<tr>
<td>Tympanitis</td>
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<td>1</td>
</tr>
<tr>
<td>Infectious and invasive diseases</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Lung infections</td>
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<td>2</td>
</tr>
<tr>
<td>Genitourinary tract infections</td>
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</tr>
<tr>
<td>Fungal otitis externa</td>
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<td>1</td>
</tr>
<tr>
<td>All kinds of checks</td>
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<td>12</td>
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<tr>
<td>Decreased heart rate</td>
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<tr>
<td>Decreased blood potassium</td>
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<tr>
<td>Elevated blood glucose</td>
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<tr>
<td>Increased blood pressure</td>
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<td>10</td>
</tr>
<tr>
<td>Various neurological disorders</td>
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<td>5</td>
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<tr>
<td>Transient ischemic attack</td>
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<tr>
<td>Aphasia</td>
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</tr>
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<td>Headache</td>
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<tr>
<td>Term</td>
<td>Experimental group (N=128)</td>
<td>Control group (N=129)</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>Subjects</td>
</tr>
<tr>
<td>Dizzy</td>
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<tr>
<td>Various injuries, poisoning and surgical complications</td>
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<td>1</td>
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<tr>
<td>Painful incision</td>
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<td>1</td>
</tr>
<tr>
<td>Various musculoskeletal and connective tissue diseases</td>
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<tr>
<td>Pain in the lower back or ribs</td>
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<tr>
<td>Respirational, thoracic, and mediastinal disorders</td>
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<td>1</td>
</tr>
<tr>
<td>Asthma</td>
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<td>0</td>
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<tr>
<td>Cough</td>
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<tr>
<td>Psychosis</td>
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<td>2</td>
</tr>
<tr>
<td>Insomnia</td>
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<td>1</td>
</tr>
<tr>
<td>Difficulty falling asleep</td>
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<tr>
<td>Restlessness</td>
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<tr>
<td>Diseases of the skin and subcutaneous tissue</td>
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<td>2</td>
</tr>
<tr>
<td>Erythema</td>
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<td>1</td>
</tr>
<tr>
<td>Rash</td>
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<td>0</td>
</tr>
<tr>
<td>Eczema</td>
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<td>1</td>
</tr>
<tr>
<td>Systemic diseases and various reactions at the site of administration</td>
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</tr>
<tr>
<td>Fever</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Chest discomfort</td>
<td>0</td>
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</tr>
<tr>
<td>Term</td>
<td>Experimental group (N=128)</td>
<td>Control group (N=129)</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>---------------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td></td>
<td>Number</td>
<td>Subjects</td>
</tr>
<tr>
<td>Diseases of the kidneys and urinary system</td>
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<tr>
<td>Oliguria</td>
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<td>Diseases of the gastrointestinal system</td>
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<tr>
<td>Constipation</td>
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<td>3</td>
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<tr>
<td>Bloating</td>
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<tr>
<td>Vomit</td>
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</tr>
<tr>
<td>Dyspepsia</td>
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</tr>
<tr>
<td>Stress ulcers</td>
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<td>1</td>
</tr>
<tr>
<td>Heart disease</td>
<td>3</td>
<td>2</td>
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<tr>
<td>Palpitation</td>
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</tr>
<tr>
<td>Heart discomfort</td>
<td>1</td>
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</tr>
<tr>
<td>Vascular and lymphatic diseases</td>
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<td>2</td>
</tr>
<tr>
<td>Hypertension</td>
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<td>1</td>
</tr>
<tr>
<td>Thrombosis</td>
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<tr>
<td>Diseases of the blood system</td>
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<tr>
<td>Anaemia</td>
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**Total subjects of adverse events**

<table>
<thead>
<tr>
<th>No. of cases (No. missing)</th>
<th>128 (0)</th>
<th>129 (0)</th>
<th>CHI2=0.03</th>
<th>P=0.8553</th>
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<tbody>
<tr>
<td>No n(%)</td>
<td>98 (76.56)</td>
<td>100 (77.52)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes n(%)</td>
<td>30 (23.44)</td>
<td>29 (22.48)</td>
<td></td>
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