

Path From Clinical Research to Implementation

Endovascular Treatment of Ischemic Stroke in the Netherlands

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ABSTRACT: Before 2015, endovascular treatment (EVT) for acute ischemic stroke was considered a promising treatment option. Based on limited evidence, it was performed in several dedicated stroke centers worldwide on selected patients. Since 2015, EVT for patients with intracranial large vessel occlusion has quickly been implemented as standard treatment in many countries worldwide, supported by the revised international guidelines based on solid evidence from multiple clinical trials. We describe the development in use of EVT in the Netherlands before, during, and after the pivotal EVT trials. We used data from all patients who were treated with EVT in the Netherlands from January 2002 until December 2018. We undertook a time-series analysis to examine trends in the use of EVT using Poisson regression analysis. Incidence rate ratios per year with 95% CIs were obtained to demonstrate the impact and implementation after the publication of the EVT trial results. We made regional observation plots, adjusted for stroke incidence, to assess the availability and use of the treatment in the country. In the buildup to the MR CLEAN (Multicenter Clinical Trial of Endovascular Treatment of Acute Ischemic Stroke in the Netherlands), a slow increase of EVT patients was observed, with 0.2% of all ischemic stroke patients receiving EVT. Before the trial results were formally announced, a statistically significant increase in EVT-treated patients per year was observed (incidence rate ratio, 1.72 [95% CI, 1.46–2.04]), and after the trial publication, an immediate steep increase was seen, followed by a more gradual increase (incidence rate ratio, 2.14 [95% CI, 1.77–2.59]). In 2018, the percentage of ischemic stroke patients receiving EVT increased to 5.8%. A well-developed infrastructure, a pragmatic approach toward the use of EVT in clinical practice, in combination with a strict adherence by the regulatory authorities to national evidence-based guidelines has led to successful implementation of EVT in the Netherlands. Ongoing efforts are directed at further increasing the proportion of stroke patients with EVT in all regions of the country.

Key Words: brain ischemia ■ ischemia ■ implementation science ■ stroke ■ thrombectomy

Endovascular treatment (EVT) in patients with acute ischemic stroke has been proven highly effective in randomized controlled trials.^{1–7} The MR CLEAN (Multicenter Clinical Trial of Endovascular Treatment of Acute Ischemic Stroke in the Netherlands) was the first to publish positive results in January 2015, immediately followed by several other trials.¹

Before the start of the MR CLEAN trial in December 2010, several studies had provided data suggesting that EVT might be beneficial, although convincing evidence was lacking.^{8,9} The Dutch stroke guidelines of 2008 mentioned EVT as a rescue treatment, preferably provided within the context of randomized trials. In the Netherlands, EVT for acute ischemic stroke was not reimbursed until 2013, when reimbursement to centers was made conditional on participation in the MR CLEAN trial. This reimbursement policy is still in place and reinforced by

See related articles, p 1928, p 1932, p 1951, p 1961, p 1969 and p 1978

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guidelines and quality criteria provided by the professional societies and endorsed by regulating authorities.

In the early 2000s, 2 stroke centers started providing EVT as an experimental treatment in selected patients, inspired by the results of early trials and by local clinical experience.¹⁰ After 2005, other centers gradually followed. Still, before initiation of the MR CLEAN trial in 2010, there were 2 centers in the Netherlands that had treated >50 patients with IAT. Currently, 17 comprehensive stroke centers provide EVT in the Netherlands for a population of 17 182 000 inhabitants.

The European Stroke Organisation recently stated that in 2030, 95% of eligible patients across Europe should have access to reperfusion therapy and EVT rates should be over 5% in all European countries.¹¹ Although considerable efforts have been made, a recent study showed large differences between countries in terms of access to appropriate acute stroke treatment.¹² Gaining understanding in the trends of EVT over time might not only provide insight into the accessibility but also about the implementation of new treatments in daily clinical practice.

In this article, we describe the trends in number of patients with acute ischemic stroke who were treated with EVT and the accessibility of EVT in the Netherlands in 3 time periods: before, during, and after the completion of the MR CLEAN trial.

METHODS

The data of the MR CLEAN TRIAL have been made publicly available at the Virtual International Stroke Trials Archive and can be accessed at <http://www.virtualtrialsarchives.org/vista/>. Individual patient data of the MR CLEAN pretrial registry and the MR CLEAN Registry cannot be made available under the Dutch law, as we did not obtain patient approval for sharing individual patient data, even in coded form. However, all syntax files and output of statistical analyses will be made available upon reasonable request.

Study Population

We analyzed data from the MR CLEAN pretrial period, the MR CLEAN trial, and MR CLEAN Registry.

In the pretrial period, we retrospectively and prospectively collected data of all patients with acute ischemic stroke who received EVT in the Netherlands from October 2002 until a center started participation in the MR CLEAN trial, which included its first patient in December 2010.¹³

Patient selection criteria and methods of the MR CLEAN trial have been reported previously.¹⁴ In short, the MR CLEAN trial was a clinical trial in which patients with a proximal intracranial arterial occlusion in the anterior circulation were randomized to either EVT with usual care or usual care alone. Treatment should be started within 6 hours after onset of stroke symptoms. All patients or their legal representatives provided written informed consent before randomization in the MR CLEAN trial. The study protocol of the MR CLEAN trial was approved by a

central medical ethics committee and the research board of each participating center.¹⁴

Directly after inclusion of the last patient in the trial by March 2014 and before the presentation of the MR CLEAN trial results at the World Stroke Conference in October 2014, all EVT-treated patients were enrolled in the MR CLEAN Registry, which is as a prospective, multicenter, observational study. For our current analysis, we used data from all patients registered until December 31, 2018.¹⁵ The MR CLEAN Registry was approved by the Medical Ethics Committee of the Erasmus MC, Rotterdam, the Netherlands (MEC-2014-235).

We assume that no patients were treated outside the MR CLEAN trial during the study period and that all patients treated before and after the trial are registered in either one of the registries.

Statistical Analysis

We analyzed differences between 3 time periods (pretrial period, MR CLEAN trial, and MR CLEAN Registry). Patients in the MR CLEAN trial who were randomized to usual care were also included, since EVT was considered in these patients.

We used Poisson regression or negative binomial regression to determine whether the incidence ratio of EVT changed during the pretrial period and MR CLEAN Registry with the denominator being the count of EVT in each year. We then computed incidence rate ratios¹⁶ with 95% CIs, using the first year of the time period as reference point. Data were checked for potential overdispersion (variance greater than the mean) to ensure that the assumptions of a Poisson distribution were met. All analyses were adjusted for the number of stroke patients per year.^{16–28}

We calculated the use of EVT as a proportion of all patients in the Netherlands who were hospitalized with acute ischemic stroke (including cerebral hemorrhages) between 2002 and 2018, which was based on reports of the Dutch Heart Association.^{22–26} Linear regression was used to estimate the number of ischemic stroke patients for years in which another definition of stroke was used or years in which only the number of patients hospitalized with acute stroke was reported.

Maps of the Netherlands at province level were created using R package tmap.²⁹ Geographic and demographic information was obtained from Statistics Netherlands and Kadaster.^{30,31} The number of EVT-treated patients by province was based on the location of first hospital admission. The density of EVT-treated patients was averaged by dividing the total number of patients by, respectively, the years of patient enrollment and number of stroke patients per province. The latter was based on anonymized data obtained from central hospital registration systems.

All statistical analyses were performed in R statistical software 3.4.2 (R Foundation for Statistical Computation, Vienna).

RESULTS

In this 16 years' time period, 6394 patients were treated with EVT. In the pretrial period (2002–2010), 514 patients were treated with EVT. During the MR CLEAN trial (2010–2014), 500 patients were included of whom 233 patients were randomized to intervention. In the ongoing

MR CLEAN Registry started directly after inclusion of the last patient in the MR CLEAN trial in March 2014, 5335 patients were registered until December 2018.

Of all treated patients, 2299 (53%) patients were men; 59% in the pretrial period, 58% in MR CLEAN trial, and 52% in the MR CLEAN Registry. The median age was 70 years (interquartile range [IQR], 58–79); 62 in pretrial patients (IQR, 51–71), 66 (IQR, 55–76) during the MR CLEAN trial, and 71 (IQR, 61–80) in the MR CLEAN Registry. The time from onset to groin puncture was 205 minutes (IQR, 155–270). A median onset-to-groin-puncture time of 237 minutes (IQR, 190–315) was observed in the pretrial population, which had increased to 260 (IQR, 210–311) in the MR CLEAN trial and decreased to 195 (IQR, 150–260) in the MR CLEAN Registry. All baseline characteristics significantly differed between study periods (Table 1).

Trend Analyses

From 2006 onward, a gradual increase in thrombectomies was observed (Figure 1). In the buildup to the MR CLEAN trial, more centers provided EVT, and a sharper increase was observed, which continued during the MR CLEAN trial. After the last inclusion in the MR CLEAN trial, the same level of increase was observed until the results of the EVT trials were presented in October 2014. After the presentation of the MR CLEAN trial results at the World Stroke Conference in October 2014, the number of patients treated with EVT increased steeply (Figure 1). During the pretrial period and following the steep increase that occurred immediately after the trial, in the MR CLEAN Registry period, a statistically significant gradual increase in EVT-treated patients per year was observed (pretrial: incidence rate ratio: 1.72 [95% CI, 1.46–2.04], $P < 0.001$; MR CLEAN Registry: incidence rate ratio: 2.14 [95% CI, 1.77–2.59], $P < 0.001$).

Regional Differences

During the pretrial period, patients were predominantly treated in Utrecht—a province in the center of the

Netherlands. During the trial phase, a similar pattern was observed, although the number of patients treated in other regions increased. After announcement of the trial results, the distribution of EVT-treated patients spread more evenly across the Netherlands (Figure 2).

Proportion of Acute Ischemic Stroke Patients Receiving EVT

In 2010, 23 771 patients were hospitalized with acute ischemic stroke in the Netherlands, of whom 170 (0.5%) received EVT. In 2014, 217 (0.8%) acute ischemic stroke patients received EVT. After the MR CLEAN trial, the percentage of acute ischemic stroke patients treated with EVT increased to 3.1% in 2015. In 2018, 29 244 patients were admitted with acute ischemic stroke of whom 1712 (5.8%) received EVT (Figure 3; Table I in the [Data Supplement](#)).

DISCUSSION

We described the trends in use of EVT before, during, and after the MR CLEAN trial expressed as the coverage of EVT in the Netherlands across different regions and the proportion of stroke patients who received EVT.

Our time-trend analysis showed increasing rates of treated patients in 3 consecutive time periods. In the pretrial period, the number of treated patients before the MR CLEAN trial in the Netherlands was low. This was probably due to conservative recommendations in the national guidelines that recognized the low level of evidence for this treatment and to the fact that EVT was not reimbursed in that time period. During the pretrial period, a strict policy regarding non-evidence-based treatments was maintained by insurance companies, government, and professional societies.

A strict national policy of evidence-based guidelines is meant to provide the best evidence-based care to the majority of patients. However, it has to be acknowledged that the pioneering centers, which provided EVT as an experimental treatment when guidelines were not yet

Table 1. Baseline Characteristics

	In Total: October 2004 to June 2016 (n=4308)	Pretrial: October 2004 to December 2010 (n=514)	MR CLEAN Trial: December 2010 to March 2014 (n=500)	MR CLEAN Registry: April 2014 to October 2017 (n=3294)	P Value
Age, y; median (IQR)	70 (58–79)	62 (51–71)	66 (55–76)	71 (61–80)	<0.001
Men, n (%)	2299 (53)	305 (59)	292 (58)	1702 (52)	<0.001
NIHSS, median (IQR)	16 (11–20)	16 (12–21)	16 (12–21)	16 (11–20)	<0.001
SBP, mmHg; mean (SD)	149 (28)	148 (24)	145 (25)	150 (28)	0.01
Intravenous alteplase treatment, n (%)	3217 (75)	323 (64)	445 (89)	2449 (75)	<0.001
Onset-to-groin-puncture time, min; median (IQR)	205 (155–270)	237 (190–315)	260 (210–311)	195 (150–260)	<0.001

mRS was missing in 373 patients; NIHSS was missing in 189 patients; SBP was missing in 189 patients. MR CLEAN Registry contains information on baseline characteristics up to October 2017. IQR indicates interquartile range; MR CLEAN, Multicenter Clinical Trial of Endovascular Treatment of Acute Ischemic Stroke in the Netherlands; mRS, modified Rankin Scale; NIHSS, National Institutes of Health Stroke Scale; and SBP, systolic blood pressure.

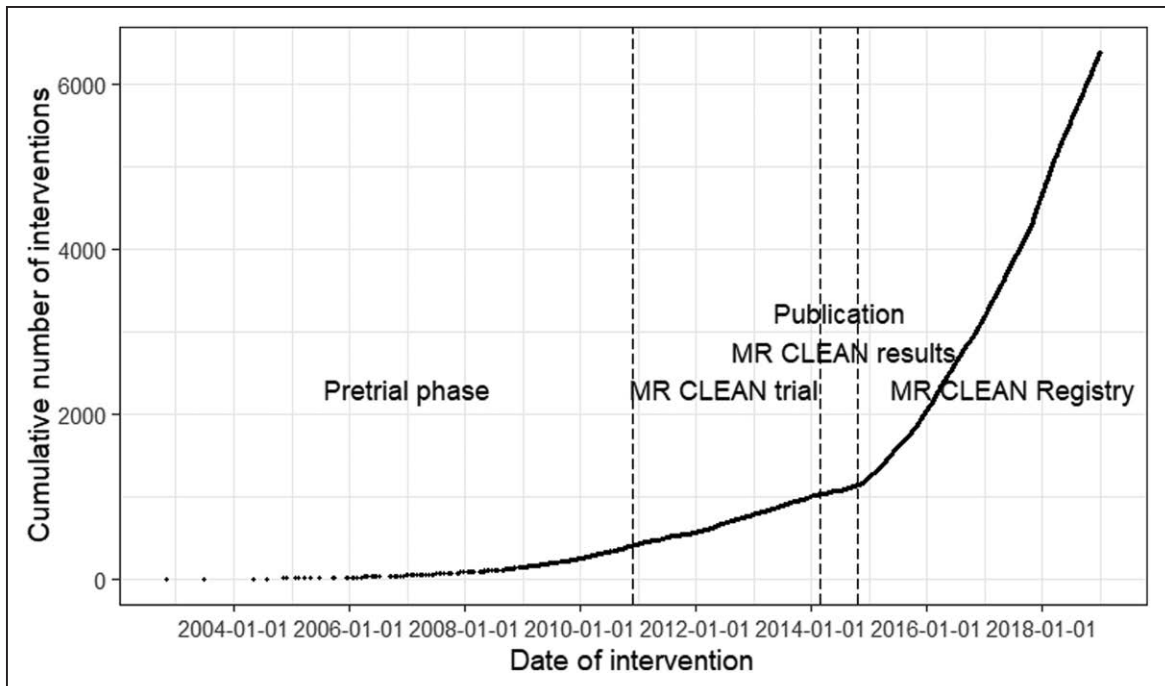


Figure 1. Trends over time regarding the use of endovascular treatment (EVT) in patients with acute ischemic stroke, presenting the observed number of EVT procedures.

MR CLEAN indicates Multicenter Clinical Trial of Endovascular Treatment of Acute Ischemic Stroke in the Netherlands.

accommodating this intervention, played an important role in the pretrial development of acute stroke networks and treatment experience necessary to successfully perform a randomized clinical trial.

The adherence to guideline-based treatment strategies continued until the steep increase of EVT-treated patients just after the results of MR CLEAN were formally announced at the World Stroke Conference in October 2014.³² From the last inclusion in the trial until the presentation of these results, the use of EVT increased with

the same level as during the MR CLEAN trial. The sharp acceleration of EVT use after October 2014 indicates that centers and physicians quickly adopted EVT and rapidly reorganized their acute stroke care to be able to provide this new treatment to more patients, even ahead of incorporation of EVT in the national guidelines in 2017.

The Netherlands belong to the countries with one of the highest annual proportion of patients with ischemic stroke receiving EVT.¹² In 2017, 5.1% of the acute ischemic stroke patients received EVT.¹² In the United States

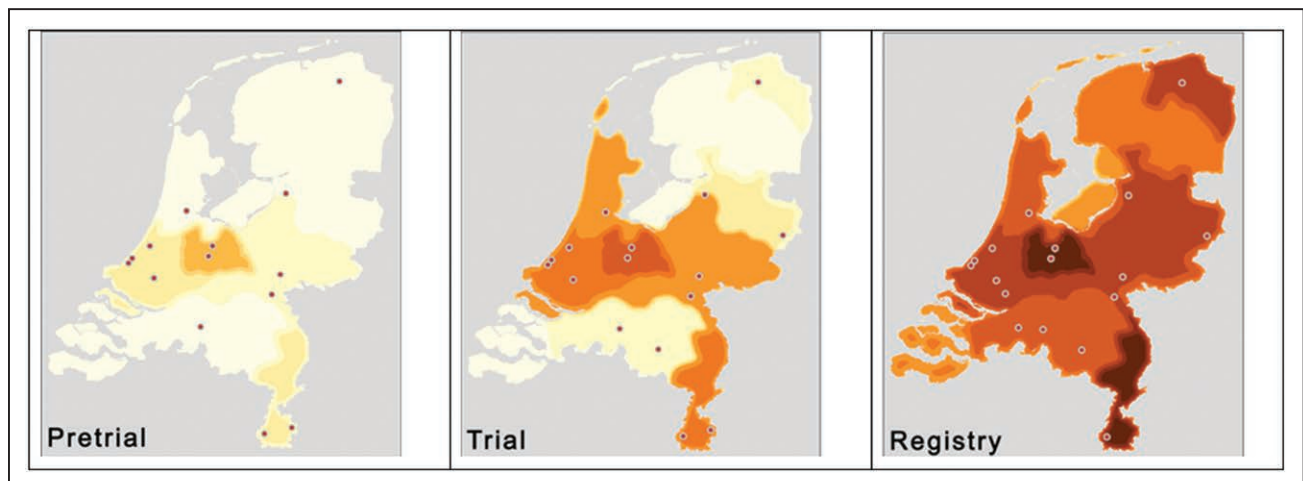


Figure 2. Maps of the coverage of endovascular treatment (EVT) in the Netherlands per province in 3 different time periods (Pretrial, MR CLEAN trial [Multicenter Clinical Trial of Endovascular Treatment of Acute Ischemic Stroke in the Netherlands], MR CLEAN Registry).

Number of EVT-treated patients for each province are indicated per province. The density of EVTs was averaged by dividing the total number of treated patients by the average incidence during the observation period in that province. The red dots indicate intervention centers.

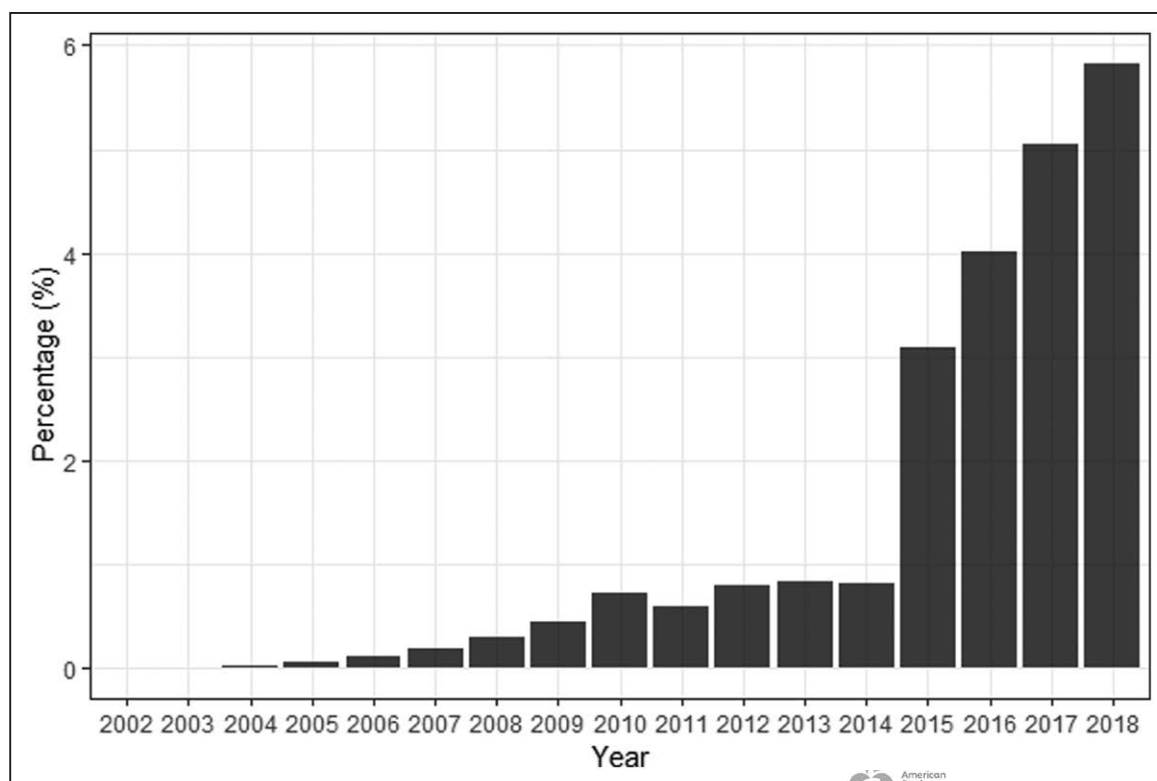


Figure 3. Proportion of ischemic stroke patients receiving endovascular treatment in the Netherlands per year.

during the same time period, 3.3% of ischemic stroke patients were treated with EVT in selected centers.³³

It has been estimated that about 10% of the patients with ischemic stroke are eligible for EVT.^{34,35} Therefore, it could be roughly estimated that almost 50% of the number of ischemic stroke patients eligible for EVT actually received this treatment in 2018. This implies that many patients who are eligible still do not receive the treatment. This can be partially explained by the fact that a lot of patients arrived >6 hours after symptom onset, and treatment of patient in this late treatment window was not yet included in national and European guidelines.^{36,37} Another explanation might be that not yet all patients who might benefit from EVT are being recognized in time prehospital and in hospital, even though CTA has been advised as standard diagnostic procedure for all patients with acute ischemic stroke.³⁸ Also, in current clinical practice, most suspected stroke patients are first transported to the nearest hospital for immediate treatment with IVT, which can lead to delay of the start of EVT and worse outcomes because of additional time needed for transfer to an endovascular capable center.³⁹

Acute stroke care in the Netherlands is organized as follows. A national network for acute medical care has been established, with expert committees for subsections for acute stroke care, trauma, obstetrics, acute psychiatry, and acute myocardial infarction. The acute stroke care expert committee consists of vascular neurologists representing all stroke centers in the region,

a GP, ambulance service coordinators, and a secretary. Every region has a regional network protocol for acute stroke care, based on the national stroke guideline and the requirements proposed by the national societies of neurology and radiology. The regional protocol prescribes the pathway from onset to ER of primary stroke center and intervention center. Triage systems are being evaluated for implementation in prehospital settings, but meanwhile, all patients are being transferred to the most nearby hospital with IVT available⁴⁰ (Figure 1 in the [Data Supplement](#)).

Our density plots show that some regions implemented EVT earlier and with a faster rate than other regions. These between-region differences indicate that access to EVT in the Netherlands can still be improved. Increasing the availability of EVT might contribute to equally divided stroke care in the Netherlands, although the number of stroke units per ischemic stroke patients is already at a high level.¹² Considering that patients treated with EVT at higher volume centers have better outcomes than those treated at lower volume centers and that time is brain, especially in EVT-eligible stroke patients,^{41–43} a careful trade-off between centralization and accessibility of acute stroke care should be made.⁴³


Experience from related medical areas, for instance from cardiology, could provide valuable lessons and some guidance. In the eighties and nineties, patients with large myocardial infarction were being treated with thrombolytics. But when the superiority of the more effective and

safer percutaneous coronary intervention (PCI) had been established, the country-wide introduction of this therapy was hampered and delayed by almost a decade by the specific requirements that the hospitals offering this form of treatment had to meet. Not infrequent and serious complications associated with the PCI procedure mandated the presence of on-site cardiac surgery in the early years following the introduction of PCI and limited the number of sites that could offer optimal treatment. Both technical and organizational developments subsequently made the requirements of on-site cardiac surgery less of an issue and gradually enabled the development of PCI programs in hospitals without on-site cardiac surgery from the year 2002 onward. Since then, the number of sites offering primary PCI for large myocardial infarctions increased from 16 to 30, more than sufficient to treat all patients with large myocardial infarctions within a reasonable time frame.⁴⁴

Inspired by this example, professional societies, governmental agencies, and insurance companies concluded

that one stroke intervention center per million inhabitants should be sufficient. Hospitals are supported in providing EVT, given the relatively small effect on hospital costs but substantial cost savings in the social service sector.^{45,46} To facilitate the development of EVT centers in the Netherlands and to ensure sufficient quality, requirements have been kept at an essential minimum of 50 EVT procedures per center per year and include 24/7 availability, sufficient facilities, and trained personnel (Table 2). These requirements were proposed by the Dutch Society for Neurology and the Dutch Society for Radiology and adopted by insurance companies and regulatory bodies. However, the requirements for EVT centers are being updated because of the extension of the time window for reperfusion treatment based on advanced perfusion imaging.⁴⁷⁻⁵¹ The national guidelines require acquisition of NCCT and CTA (or magnetic resonance imaging/MRA) in all patients with acute ischemic stroke and are being updated with perfusion imaging for late-window ischemic stroke patients.

Table 2. Quality Criteria for Primary Stroke Centers Providing Intravenous Alteplase Treatment and for Stroke Intervention Centers Providing Endovascular Treatment for Ischemic Stroke, Established by the Professional Societies for Radiology and Neurology in 2017

Primary stroke centers should	
admit and treat at least 100 acute stroke patients annually (mean of last 3 y)	
have a median door-to-needle time of <45 min	
have CT and CTA, of cervical and intracranial vessels 24/7 available, with direct assessment provided by or supervised by a radiologist	
have treatment with intravenous alteplase 24/7 available, with the treatment performed by or under supervision of a neurologist, who has direct access to neuroimaging	
have a stroke team 24/7 available, with a stroke nurse under supervision of a neurologist	
have stroke unit with 24/7 care and 24/7 admission through ER	
have neurosurgery available 24/7 or collaboration with a nearby neurosurgical center	
have a registry of acute stroke patients, which includes the percentage of patients treated with intravenous alteplase and the number of patients admitted within 4.5 h after onset of stroke	
participate in a regional stroke service and have a regional coordinator	
have arrangements with an intervention center for endovascular treatment and with the regional ambulance service for rapid transfer of patients eligible for endovascular treatment	
Stroke intervention centers should	
fulfill the criteria for primary stroke centers	
have a multidisciplinary team at least consisting of a neurologist, radiologist, interventionalist, and anesthesiologist	
provide EVT on a 24/7 basis with the multidisciplinary team	
have arrangements with at least one other center in the same region to provide EVT when because of unusual circumstances EVT is not available in their own center	
have at least 2 angio suites, of which one is readily available with sufficient and appropriate personnel	
be equipped with an intensive care unit and a stroke unit	
have a local protocol, which includes description of logistics, responsibilities of all involved professionals, patients' safety, and benchmarks for door-to-needle and door-to-groin-puncture time	
have neurologists with vascular expertise available 24/7	
have at least 3 interventionalists	
perform at least 50 EVT procedures per year	
have at least 20 EVT procedures per interventionalist per year (procedures done by 2 interventionalists count for both)	
have median door-to-groin-puncture times of <60 min	
have a local registry of quality-of-care parameters concerning logistics, complications, and technical as well as clinical outcomes (at least door-to-groin-puncture time and onset-to-groin-puncture time, eTICI, and mRS at 3 mo)	

CT indicates computed tomography; CTA, computed tomography angiography; ER, emergency room; eTICI, expanded Thrombolysis in Cerebral Infarction; EVT, endovascular treatment; and mRS, modified Rankin Scale.

More than a decade ago, criteria were established by the national professional societies that require a 2-year training in neurointervention with certification that is open to all medical specialties but in practice to neurologists, radiologists, and neurosurgeons.⁵² Almost all interventionists in the Netherlands are radiologists. For general interventional radiologists who want to qualify for EVT of ischemic stroke, a short additional training is required that amounts to doing at least 25 thrombectomies, 50 digital subtraction angiographies, 200 other endovascular procedures, and assessment of 200 NCCT and ≥ 50 head/neck CTA or MRAs under supervision.

Interestingly, during the trial, onset-to-groin times had increased by about 1 hour, and after the trial, a gradual decrease was noted. The increase may be attributed to the consent and randomization procedure in the trial, whereas improved awareness, logistics, and increasing experience has led to the gradual decrease after the trial. Median age of EVT treated patients increased, likely because trial results and guidelines point out that high age by itself should not be considered as a contraindication for EVT⁵³ (Figure II through VI in the [Data Supplement](#)).

Our study has some limitations. No information about the residence of the EVT-treated patients was available for all time periods. Therefore, we estimated the coverage of EVT in the Netherlands based on the first hospital admission. Since not all patients are at home at the moment of their stroke onset and the first hospital is often close to the place of stroke onset, this should reflect daily clinical care.

Our study only describes EVT in the Netherlands, and it does only touch upon factors that have facilitated its rapid implementation. Comparisons with other countries may help in this regard. Still, several factors may have played an important role in the implementation of EVT in the Netherlands, including the dense population (17 million people living on an area of 33671 km², for an average population density of 510/km²), the dense highway network, the large number of primary stroke centers (85, 5 per million inhabitants) and EVT centers (17, 1 per million inhabitants),¹² and last, an ambulance network that has to comply with the requirement that every patient should be picked up within 15 minutes after calling 112 and should be delivered at the ER of the most nearby primary stroke center within 30 minutes.

CONCLUSIONS

A well-developed infrastructure, a pragmatic approach toward the use of EVT in clinical practice, in combination with a strict adherence by the regulatory authorities to national evidence-based guidelines has led to successful implementation of EVT in the Netherlands. Ongoing efforts are directed at further increasing the

proportion of stroke patients with EVT in all regions of the country.

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Disclosures

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APPENDIX

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