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Acute stroke imaging protocols and decision-making criteria for endovascular thrombectomy in acute ischemic stroke: a nationwide survey of thrombectomy-capable centers in Korea

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Abstract

Background and purpose Standardized imaging protocols and eligibility criteria are essential for optimizing endovascular thrombectomy (EVT) in acute ischemic stroke. This study investigated current imaging protocols and EVT eligibility criteria across different time windows in Korea.

Methods This nationwide cross-sectional survey used a comprehensive 58-item electronic questionnaire was distributed to stroke neurologists, vascular neurosurgeons, and interventional neuroradiologists at 77 thrombectomy-capable stroke centers (TSCs) certified by the Korean Stroke Society. The survey assessed acute imaging protocols and EVT eligibility criteria across time windows: early (< 6 h), late (6–16 h and 16–24 h), and extended (24–48 h) from symptom onset. Responses were collected from July–December 2024.

Results Forty-nine physicians from 45 (58.4%) centers responded. Computed tomography (CT)-based imaging was the predominant modality across all time windows (< 6 h: 71.1%; 6–16 h: 51.2%; 16–24 h: 52.4%; 24–48 h: 40%). The proportion of TSCs implementing perfusion imaging increased with longer time windows (< 6 h: 73.3%; 6–16 h: 86.0%; 16–24 h: 88.1%; 24–48 h: 100%; *p* for trend < 0.01). Vendor-provided automated software was most commonly used for detecting perfusion abnormalities, while among centers employing advanced automated post-processing software, Rapid Processing of Perfusion and Diffusion software was the predominant program. Physicians used perfusion-based criteria commonly in late time windows: 32 (68.1%) at 6–16 h, 31 (67.4%) at 16–24 h.

Conclusions This nationwide multicenter survey revealed substantial heterogeneity in imaging protocols and EVT eligibility criteria among Korean TSCs, underscoring the need for standardized imaging protocols and eligibility criteria for EVT.

Keywords Acute stroke, Perfusion imaging, Thrombectomy, Eligibility criteria

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Introduction

Endovascular thrombectomy (EVT) is the established standard of care for acute ischemic stroke (AIS) caused by large vessel occlusion (LVO) [1]. The diffusion-weighted imaging (DWI) or computed tomography perfusion (CTP) assessment with clinical mismatch in the triage of wake-up and late-presenting strokes undergoing neurointervention with Trevo (DAWN) and the endovascular therapy following imaging evaluation for ischemic stroke 3 (DEFUSE-3) trials demonstrated the efficacy of EVT beyond 6 h from symptom onset in selected patients based on DWI or CTP assessment with clinical mismatch [2, 3]. These pivotal trials employed advanced imaging protocols and eligibility criteria, facilitated by advanced automated post-processing software such as Rapid Processing of Perfusion and Diffusion (RAPID) software (iSchemaView, Menlo Park, CA, USA) [2, 3]. Consequently, recent stroke guidelines recommend advanced imaging modalities to guide EVT decisions for patients presenting beyond 6 h[4]. However, substantial gaps remain between guideline-based recommendations and real-world clinical practice, particularly in the later time windows (>6 h)[5, 6].

In South Korea, EVT has rapidly expanded alongside the nationwide development of thrombectomy-capable stroke centers (TSCs) and increasing emphasis on timely reperfusion therapy. National clinical practice guidelines recommend that each center develop its own imaging pathway for identifying target mismatch in late-presenting patients[7], reflecting variation in local infrastructure and resource availability rather than a standardized national protocol. Consequently, substantial heterogeneity in imaging workflows and EVT eligibility criteria persists across Korean centers, especially in the late window [6].

Understanding current real-world imaging practices and eligibility criteria for EVT in Korea is critical for establishing standardized care and informing policy development. However, data on imaging-based eligibility criteria for EVT beyond 6 h remain limited in South Korea.

Therefore, we conducted a nationwide survey to investigate imaging protocols used to determine EVT eligibility for patients with AIS presenting beyond 6 h from stroke onset at thrombectomy-capable stroke centers (TSCs) in South Korea.

Methods

Study design, settings, and participant selection

The survey targeted 77 TSCs certified by the Korean Stroke Society and designated as local or regional emergency medical centers by the Korean Ministry of Health and Welfare. A total of 82 participants were invited via email between July 2024 and December 2024. The 82 invited participants were board-certified stroke neurologists, vascular neurosurgeons, or interventional neuroradiologists working at TSCs certified by the Korean Stroke Society. These specialists were selected because they are directly involved in acute stroke imaging decisions and EVT workflows within their respective centers. Only clinicians who routinely participate in imaging-based triage for AIS were included. The survey was developed and administered using a modified version of Dillman's tailored design method, incorporating pre-survey notifications and up to five follow-up attempts [8]. Informed consent to participate was obtained electronically from all respondents prior to the initiation of the survey. This study was approved by the Institutional Review Board of Yonsei University College of Medicine (approval number: 4–2023-1025).

Survey questionnaire

The questionnaire, developed in Korean using Google Forms, aimed to comprehensively evaluate current imaging protocols and eligibility criteria for selecting patients with AIS for EVT beyond 6 h from symptom onset in South Korea. Participants selected the imaging protocol type that most accurately reflected the routine institutional workflow used to evaluate EVT eligibility in daily practice. Because all respondents were specialists directly responsible for acute stroke imaging interpretation and endovascular decision-making, they were fully qualified to provide detailed information on imaging components used at their centers. An English version of the questionnaire is provided in the Appendix. The survey instrument was developed by the authors and refined through multiple rounds of discussion within the study team. The final questionnaire comprised 58 items divided into a general section and several sections based on symptom-onset-to-visit intervals: an early time window (< 6 h), a late time window (subdivided into 6–16 h and 16–24 h), and an extended time window (24–48 h). The subdivision of the late time window followed definitions from the DAWN and DEFUSE-3 trials [2, 3].

The general section collected demographic and institutional information, including participants' age, medical specialty, hospital type (e.g., academic, secondary, or primary care facility), average weekly EVT volume, and institutional time limits for EVT eligibility following symptom onset.

For each time window, respondents were asked to indicate the imaging protocols routinely applied at their institutions and the clinical or imaging criteria they personally used to determine EVT eligibility. Respondents specified whether they followed major late-window EVT criteria (e.g., DAWN or DEFUSE-3) or applied their own individual thresholds, including NIHSS, pre-stroke mRS, infarct extent (ASPECTS or core volume), and other

relevant parameters. These items were presented as single- or multiple-choice questions, with optional free text fields for additional details. Imaging protocols for evaluating EVT eligibility were categorized into three types: computed tomography (CT)-based, magnetic resonance (MR)-based, and sequential CT-then-MR-based protocols. Participants selected their protocol type and provided details regarding specific imaging components used. For CT-based protocols, participants reported whether computed tomography angiography (CTA; single-phase or multiphase) and/or CT perfusion were routinely performed. For MR-based protocols, the use of sequences, including DWI, fluid-attenuated inversion recovery (FLAIR), gradient-recalled echo (GRE), susceptibility-weighted imaging (SWI), T1- and T2-weighted imaging (T1WI, T2WI), T1-weighted contrast-enhanced imaging (T1CE), time-of-flight magnetic resonance angiography (TOF-MRA), contrast-enhanced MRA, neck MRA, and MR perfusion (MRP), was assessed. Sequential protocols captured imaging elements from both CT and MR modalities.

The survey also assessed the availability and use of perfusion imaging and its interpretation methods, including advanced automated post-processing software (e.g., RAPID, Olea, MIStar), vendor-provided automated software, and visual inspection. The timing of perfusion imaging and automated software adoption was also recorded.

Table 1 Baseline characteristics

Hospital category	
Tertiary hospital	37 (82.2)
Secondary hospital	8 (17.8)
Number of beds per hospital, mean ± SD	950.0 ± 462.0
Departments of interventionist	
Neurology	31 (68.9)
Neurosurgery	31 (68.9)
Radiology	22 (48.9)
No. of operators, median (IQR)	3 (1.0)
No. of EVTs per week, median (IQR)	1 (1.0)
Centers performing EVT in each time period, *n* (%)	
6 h <	45 (100)
6–16 h	43 (95.6)
16–24 h	42 (93.3)
24–48 h	23 (44.4)

All values in this table represent center-level data, rather than physician-level responses

Values are number (%), median (interquartile range), or mean ± standard deviation

The number of beds per hospital is presented as mean ± standard deviation

SD standard deviation, *IQR* interquartile range, *EVT* endovascular thrombectomy

Comparison of imaging protocols and eligibility criteria for EVT by time intervals from symptom onset

Based on responses provided in the general section, the following items were evaluated for each specified time interval: (1) availability of EVT within each time window; (2) imaging protocol type (CT-based, MR-based, or sequential CT-then-MR), and its specific components as described above; (3) eligibility criteria, classified according to the primary imaging features used to determine EVT candidacy: (a) any LVO (all patients with LVO considered as EVT candidates), (b) perfusion imaging-based, (c) Alberta Stroke Program Early CT Score (ASPECTS) [9]- and/or collateral status-based, (d) other specific criteria (e.g., DWI–FLAIR mismatch, core–clinical mismatch), and (e) no specific criteria (based on the discretion of the on-call physician); and (4) specific criteria applied within each eligibility category, such as the use of DAWN or DEFUSE-3 criteria if perfusion imaging-based eligibility criteria was used, or threshold ASPECTS cutoff value if ASPECTS- and/or collateral-based criteria was employed. When perfusion imaging-based eligibility was used, the method of perfusion status interpretation was also recorded: (i) advanced automated post-processing software (RAPID, Olea, MiStar), (ii) vendor-provided automated software, or (iii) visual inspection. These data were used to compare differences in imaging protocols and eligibility criteria across all included time windows.

Statistical analysis

Survey responses were recorded electronically and stored in a secure database. Data are presented as mean ± standard deviation (SD), median with interquartile range (IQR), or percentage (%), as appropriate. Between-group differences were analyzed using Student's t-test or Chi-square test, as appropriate. A trend test was used to assess changes in imaging protocols and eligibility criteria across time intervals beyond 6 h from symptom onset. Statistical significance was defined as a two-sided p-value < 0.05. All analyses were performed using R statistical software (version 4.3.1; R Foundation for Statistical Computing, Vienna, Austria) and SPSS for Windows (version 27; SPSS, Chicago, IL, USA).

Results

Among the 77 TSCs surveyed, 49 physicians from 45 centers (58.4%) responded, representing a total of 84 interventionists, including stroke neurologists ($n = 31$, 36.9%), vascular neurosurgeons ($n = 31$, 36.9%), and interventional neuroradiologists ($n = 22$, 26.2%). Participating TSCs comprised 37 academic hospitals and eight secondary hospitals. The median number of interventionists per center was three (IQR, 2–4), and the median number of EVT procedures performed per week was one (IQR, 0–2) (Table 1). Of the 45 responding TSCs, 43 (95.6%)

reported performing EVT within the 6–16 h window, 42 (93.3%) within the 16–24 h window, and 20 TSCs (44.4%) performed EVT for AIS beyond 24 h (up to 48 h) (Table 1).

Imaging modality according to time windows

CT-based protocols were the most commonly used across all time windows ($n = 32$, 71.1% in < 6 h; $n = 22$, 51.2% in 6–16 h; $n = 22$, 52.4% in 16–24 h; $n = 8$, 40% in 24–48 h), followed by sequential CT-then-MR-based protocols ($n = 11$, 24.4%; $n = 15$, 34.9%; $n = 13$ 31.0%; $n = 8$, 40%, respectively) and MR-based protocols ($n = 2$, 4.4%; $n = 6$, 14.0%; $n = 7$, 16.7%; and $n = 4$, 20%, respectively) (Table 2; Fig. 1). All centers employing CT-based protocols incorporated CTA, most with multiphase CTA ($n = 22$, 68.8%) and the remainder with single-phase CTA ($n = 10$, 31.2%). Among centers applying sequential CT-then-MR-based protocols, multiphase CTA ($n = 6$–8, 54.5–66.7%) and MRI sequences such as DWI followed by GRE or SWI and FLAIR (DWI, 100%; GRE or SWI, 75–92.3%; FLAIR, 62.5–76.9%) were frequently used. In MR-based protocols, the most frequently applied configuration—used by all but two TSCs—included a full MR sequence comprising DWI, FLAIR, GRE or SWI, T1WI, T2WI, T1CE, TOF-MRA, contrast-enhanced MRA, neck MRA, and MRP (2 of 2 [100%] in < 6 h, 4 of 6 [75.0%] in 6–16 h, 5 of 7 [71.4%] in 16–24 h, and 3 of 4 [75%] in 24–48 h). Among the two TSCs not using full MR sequences, one lacked T1CE imaging and MRP, and the other lacked contrast-enhanced MRA (Table 2). In the late time window, nine centers among the TSCs that primarily utilized a CT-based protocol in the early window switched their protocol to include MR imaging (three adopting MR-based protocols and six adopting sequential CT-then-MR-based protocols). In the extended time window, although CT-based protocols remained the most used, the proportion of protocols incorporating MR imaging (either MR-based or sequential CT-then-MR) increased ($n = 20$–21, 48% in the late time window vs. $n = 14$, 60% in the extended time window) (Fig. 1).

Perfusion imaging was widely adopted across all time windows, with usage progressively increasing as the time window lengthened (< 6 h: $n = 33$, 73.3%; 6–16 h: $n = 37$, 86.0%; 16–24 h: $n = 37$, 88.1%; >24 h: $n = 20$, 100%; p for trend < 0.01). Among the 37 TSCs using perfusion imaging in the late time window (6–24 h), CTP was performed in 24–25 (64.8–67.6%) centers, MRP in 10 (27.0%) centers, and both modalities in 2–3 (5.4–8.1%) TSCs. Imaging protocol use did not differ by the hospital category ($p = 0.78$) (Table 2 and Fig. 1).

Within the late time window, perfusion imaging was incorporated in 22 centers employing CT-based protocols (81.8% for 6–16 h, 86.4% for 16–24 h), in 6–7 centers using MR-based protocols (83.3% for 6–16 h,

Table 2 Imaging protocols according to time from onset to visit

Time window	< 6 h ($n = 45$)	6–16 h ($n = 43$)	16–24 h ($n = 42$)	24–48 h ($n = 20$)
Total hospitals				
Perfusion [*]	33 (73.3)[*]	37 (86.0)[*]	37 (88.1)[*]	20 (100)[*]
Automated post-processing[†]	30 (90.9)	32 (86.5)	32 (76.2)	17 (85)
RAPID program use	12 (36.4)	13 (30.2)	13 (31.0)	7 (35)
CT-based hospitals	32	22	22	8
NCCT + CTA included	32 (100)	22 (100)	22 (100)	8 (100)
Multiphase CTA	22 (68.8)	15 (68.2)	15 (68.2)	8 (100)
Perfusion	24 (75)	18 (81.8)	19 (86.4)	8 (100)
Automated post-processing[†]	22 (91.7)	16 (88.9)	16 (84.2)	7 (87.5)
RAPID program use	7 (29.2)	5 (27.8)	5 (26.3)	3 (37.5
MR-based hospitals	2	6	7	4
Full MR sequence[‡]	2 (100)	4[§] (75)	5[§] (71.4)	3 (75)[‖]
Perfusion	2 (100)	5 (83.3)	6 (85.7)	4 (100)
Automated post-processing[†]	2 (100)	4 (80)	5 (83.3)	2 (50)
RAPID program use	0	1 (20)	1 (16.7)	1 (25)
CT-then-MR-based hospitals	11	15	13	8
CT sequences				
NCCT	11 (100)	15 (100)	13 (100)	8 (100)
CTA	11 (100)	14 (93.3)	12 (92.3)	8 (100)
Multiphase CTA	6 (54.5)	9 (64.3)	8 (66.7)	5 (62.5)
MR sequences				
DWI only	2 (18.2)	1 (6.7)	1 (7.7)	2 (25)
DWI + MRP	0 (0)	1 (6.7)	0 (0)	0 (0)
DWI + GRE or SWI	1 (9.1)	2 (13.3)	2 (15.4)	1 (12.5)
DWI + FLAIR + GRE or SWI	3 (27.3)	3 (20.0)	3 (25)	2 (25)
DWI + FLAIR + GRE or SWI + T2WI	1 (9.1)	1 (6.7)	1 (7.7)	0 (0)
DWI + GRE or SWI + FLAIR + MRP	2 (18.2)	2 (13.3)	2 (15.4)	1 (12.5)
DWI + GRE or SWI + FLAIR + TOF + MRP	1 (9.1)	3 (20.0)	3 (25)	2 (25)
Full MR sequence	1 (9.1)	2 (13.3)	1 (7.7)	0 (0)
Perfusion	7 (63.6)	14 (93.3)	12 (92.3)	8 (100)
CTP	4 (57.1)	6 (42.9%)	6 (50.0%)	5 (62.5%)
MRP	2 (28.6)	5 (35.7%)	4 (33.3%)	3 (37.5%)
Both CTP and MRP	1 (14.3)	3 (21.4%)	2 (16.7%)	0 (0.0%)
Automated post-processing[†]	6 (85.7)	12 (85.7)	11 (91.7)	7 (87.5)
RAPID program use	5 (71.4)	7 (50.0)	7 (58.3)	3 (37.5)

Values are number (%), median (interquartile range), or mean ± standard deviation

NCCT noncontrast computed tomography, *CTA* computed tomography angiography, *MR* magnetic resonance, *CT* computed tomography, *SWI* susceptibility-weighted imaging, *CTP* computed tomography perfusion

[*] p for trend < 0.001

[†] Automated post-processing includes Rapid Processing of Perfusion and Diffusion (RAPID), other advanced automated post-processing software, and vendor-provided automated software

[‡] DWI, diffusion-weighted imaging; FLAIR, fluid-attenuated inversion recovery; GRE, gradient-recalled echo; T1WI, T1-weighted imaging; T2WI, T2-weighted imaging; T1CE, T1 contrast-enhanced imaging; TOF-MRA, time-of-flight magnetic resonance angiography; contrast-enhanced MRA; MRP, magnetic resonance perfusion imaging

[§] One case lacked T1CE imaging and perfusion data; the other case lacked contrast-enhanced MRA

[‖] One case without contrast-enhanced MRA and T1CE imaging

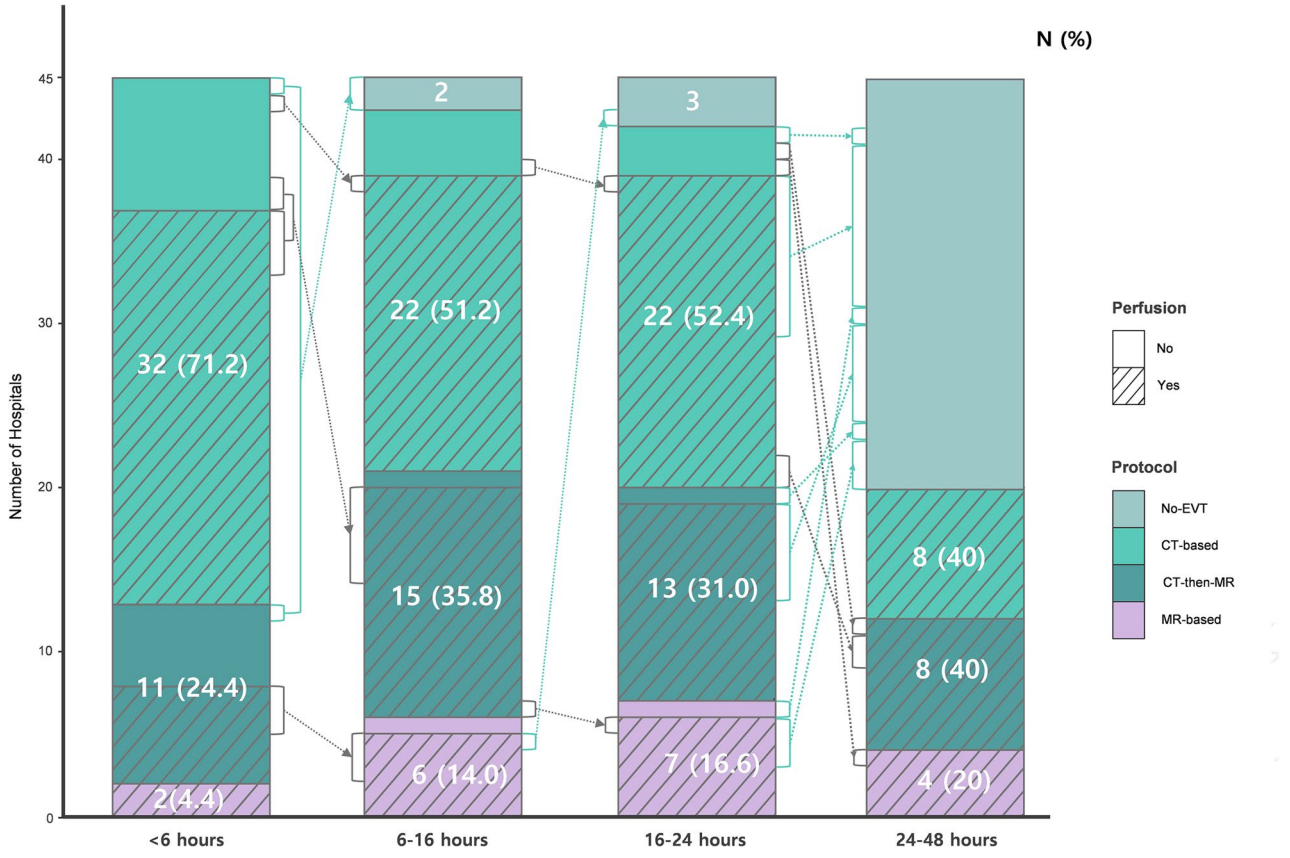

Fig. 1 Bar graph of imaging protocols assessing endovascular thrombectomy eligibility according to the onset-to-visit time window. Among the 45 thrombectomy-capable stroke centers (TSCs), imaging protocols were categorized by adoption proportion across four-time windows (< 6 h, 6–16 h, 16–24 h, and 24–48 h). Protocol types included CT-based, sequential CT-then-MR, and MR-based strategies. Shaded bar segments indicate the number of centers incorporating perfusion imaging into each protocol. CT, computed tomography; MR, magnetic resonance; EVT, endovascular thrombectomy; TSC, thrombectomy-capable stroke center

85.7% for 16–24 h), and in 12–14 centers using sequential CT-then-MR protocols (93.3% for 6–16 h, 92.3% for 16–24 h). Among centers utilizing sequential CT-then-MR-based protocols, perfusion imaging was included in the initial CT scan in 6 (42.9%) (6–16 h window) and 6 (50.0%) (16–24 h window) centers, in the subsequent MR scan in 5 (35.7%) and 4 (33.3%), and in both modalities in 3 (21.4%) and 2 (16.7%) centers, respectively (Table 2 and Fig. 1).

Eligibility criteria based on imaging protocols with specific considerations

Perfusion assessment modalities in TSCs were evaluated. Vendor-provided automated software was the most commonly used method for detecting perfusion abnormalities, applied in 16 (48.5%) at < 6 h, 16 (43.2%) at 6–24 h, and 7 (35.0%) at > 24 h centers. Advanced automated post-processing software, available in 16 (43.2%) centers during the 6–24 h window, with RAPID being the most frequently applied tool (13 centers), accounting for approximately 35% of centers across all time windows. Visual inspection alone was used in 3–5 (9.1–20.0%) centers. Adoption of perfusion imaging and automated tools, including RAPID, increased progressively after 2016 (Fig. 2, Supplemental Fig. 1).

Perfusion imaging-based eligibility criteria were the most applied selection criteria beyond the 6-h window ($n = 31–32$, 67.4–68.1% in the late time window; $n = 12$, 52.2% in the extended time window). ASPECTS- and/or collateral status-based criteria were the second most applied in the late time window ($n = 7$, 14.9% in the 6–16 h window, $n = 7$, 15.2% in the 16–24 h window) (Fig. 3). When using perfusion imaging-based criteria, the DEFUSE-3 criteria were more frequently used than the DAWN criteria in the 6–16 h window ($n = 16$, 47.0% vs. $n = 4$, 11.8%), whereas both criteria were used equally ($n = 10$, 30.3% each) in the 16–24 h window. In the extended time window, the DEFUSE-3 criteria remained more commonly applied than the DAWN criteria ($n = 4$, 33.3% vs. $n = 3$, 25.0%) (Fig. 4).

Among physicians not using perfusion-based criteria in the late time window, ASPECTS- and/or collateral status-based criteria were most common ($n = 7$, 14.9% in the 6–16 h window; $n = 7$, 15.2% in the 16–24 h window;

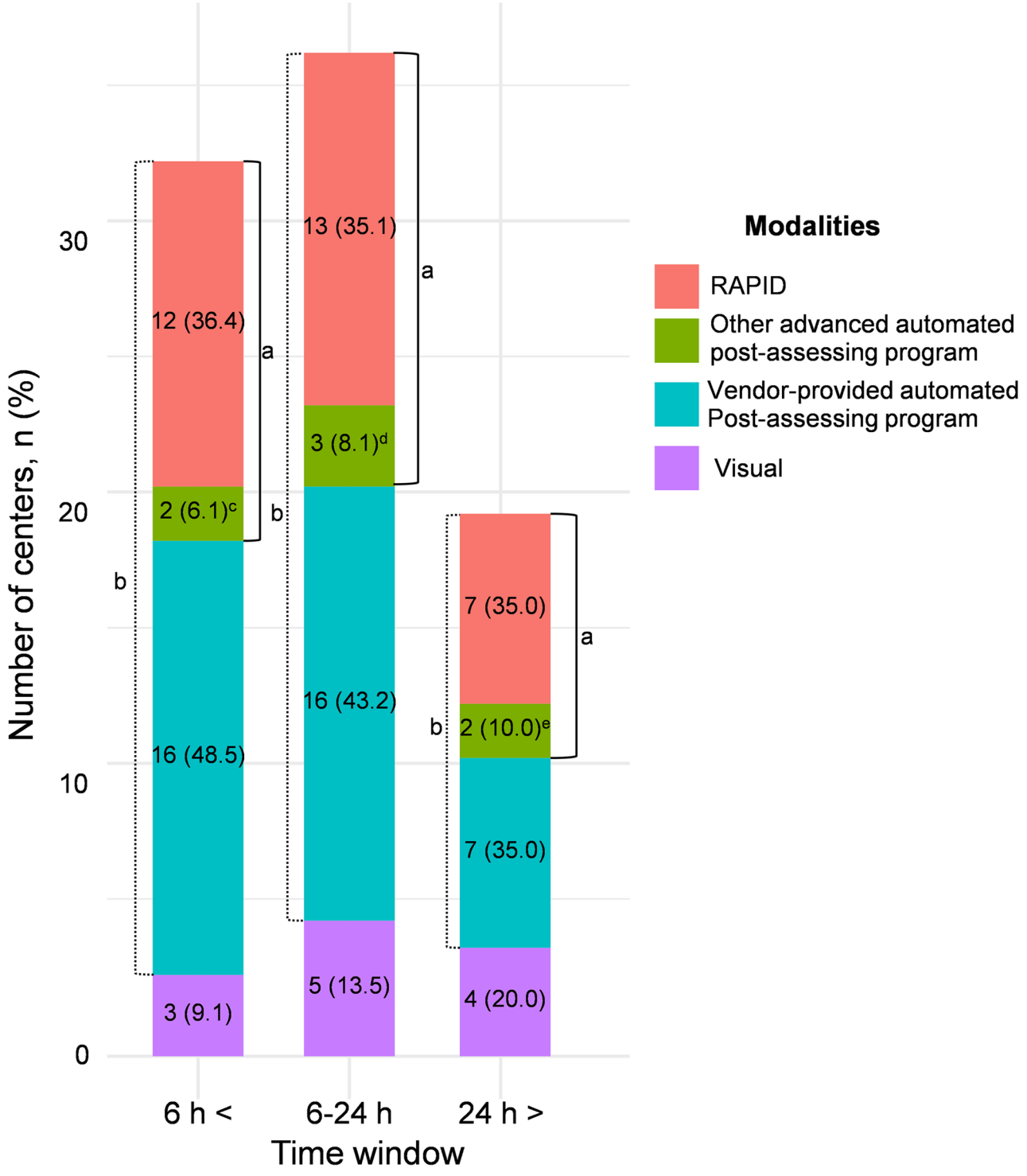

Fig. 2 Modalities assessing perfusion imaging according to time windows. Vertical stacked bars represent centers performing perfusion imaging within each time window. Numbers within each segment indicate the number and percentage of centers using each modality [a] Parentheses indicate the proportion of centers employing advanced automated post-processing software [b] Other specific software comprised JLK Inspection™, Heuron, TeraRecon iNtuition™, and Olea Sphere™ [c] TeraRecon iNtuition™, Olea Sphere™, Heuron, and two JLK Inspection™ [d] Olea Sphere™ and two JLK Inspection™ RAPID, Rapid Processing of Perfusion and Diffusion (iSchemaView Inc., Menlo Park, CA, USA)

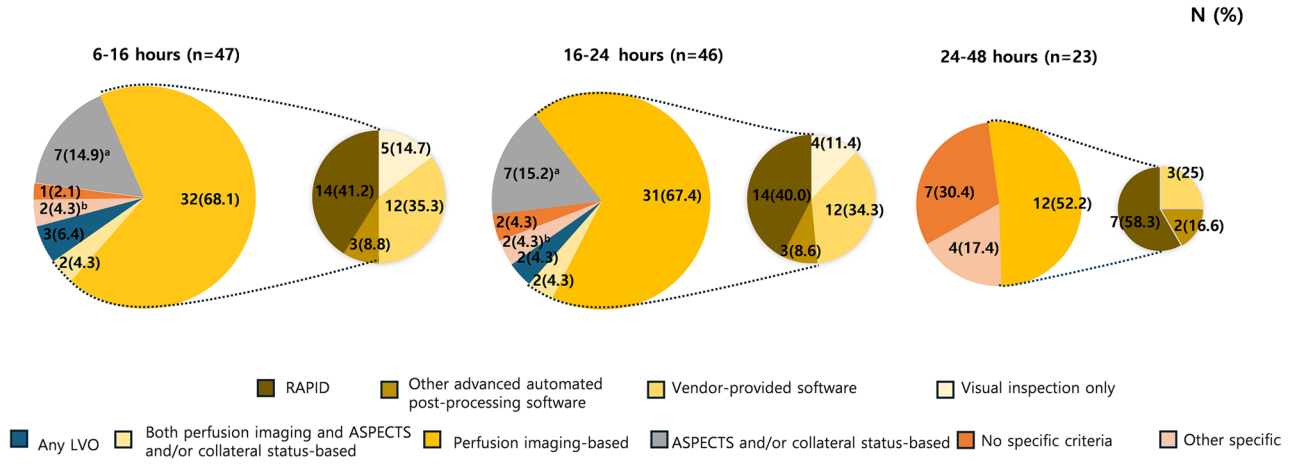

Fig. 3 Eligibility criteria for endovascular thrombectomy according to onset-to-visit time. Physicians in thrombectomy-capable stroke centers (TSCs) indicated their principal strategies for evaluating eligibility for endovascular thrombectomy (main pie charts, left in each panel). For physicians using perfusion imaging-based eligibility criteria, the perfusion assessment method was also examined (inset pie charts, right in each panel). Perfusion imaging-based eligibility (yellow) was the most frequently used criterion across all time windows. ASPECTS- and/or collateral status-based criteria (gray) were the second most used in the late time window. A minority of physicians treated all patients with LVO regardless of imaging profile (any LVO, navy), applied other specific criteria (light salmon), or used no specific criteria (dark orange). Among physicians using perfusion imaging-based eligibility criteria, RAPID (dark brown, inset pie charts) was the most frequently used assessment modality [a] Includes six physicians using CT-ASPECTS and one using DWI-ASPECTS as primary criteria [b] Two physicians applied core–clinical mismatch criteria, with the clinical thresholds defined as NIHSS ≥ 5 or ≥ 6 ASPECTS, Alberta Stroke Program Early CT Score; CT, computed tomography; DWI, diffusion-weighted imaging; LVO, large vessel occlusion; NIHSS, National Institutes of Health Stroke Scale; RAPID, Rapid Processing of Perfusion and Diffusion (iSchemaView Inc., Menlo Park, CA, USA); TSC, thrombectomy-capable stroke center

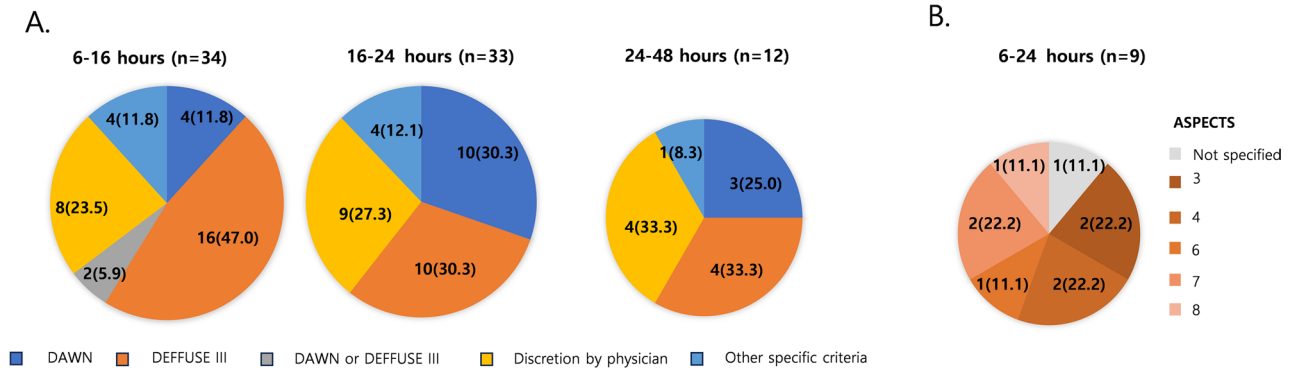

Fig. 4 Detailed perfusion imaging-based eligibility criteria and cutoff threshold of the ASPECT score. Panel **A** shows the distribution of specific perfusion imaging-based eligibility criteria across time windows. Penumbra or core volume thresholds derived from the DAWN or DEFUSE 3 criteria were most frequently applied. A substantial proportion of physicians reported no fixed mismatch threshold for EVT eligibility (6–16 h: 8 [23.5%]; 16–24 h: 9 [27.3%]; 24–48 h: 4 [33.3%]). Ten physicians employing ASPECTS- and/or collateral status-based criteria specified their cutoff values for EVT eligibility; among these, one used DWI-ASPECTS (Panel **B**) ASPECTS, Alberta Stroke Program Early CT Score; DWI, diffusion-weighted imaging; EVT, endovascular thrombectomy

and $n = 0$, 0% in the extended time window), followed by any LVO or other specific criteria. Among those using ASPECTS- and/or collateral status-based criteria, the median ASPECTS threshold for EVT eligibility was 5 (IQR, 3.5). In the 6–16 h window, 3 of 47 centers (6.4%) treated any LVO regardless of the imaging profile, and in the 16–24 h window, 1 of 46 centers (4.3%) did so. Others applied center-specific criteria that did not rely solely on perfusion imaging, or ASPECTS- and/or collateral status-based criteria ($n = 2$, 6.4% in the 6–24 h window; $n = 4$, 17.4% in the extended window). Two physicians reported no specific eligibility criteria within this time window at their centers. Decisions without predetermined eligibility criteria became progressively more common with longer presentation windows, increasing from 1 of 47 participants (2.1%) in the 6–16 h window to 2 of 46 (4.3%) in the 16–24 h window, and 7 of 23 (30.4%) in the 24–48 h window. Eligibility criteria did not differ by hospital category or number of neurointerventionists (hospital category, $p = 0.17$; number of neurointerventionists, $p = 0.64$) (Fig. 3).

Some respondents provided additional open-ended criteria to supplement the primary eligibility criteria. For instance, even at centers routinely performing EVT for all

patients with LVO, clinical limitations such as poor baseline medical conditions prompted the use of DEFUSE-3 criteria or an ASPECTS cutoff of 5. Additionally, of the seven respondents who reported using other specific criteria, three based their decisions on a core–clinical mismatch incorporating the National Institutes of Health Stroke Scale (NIHSS) score (Supplementary Table 1)[10].

Discussion

This nationwide survey provides the first comprehensive assessment of imaging modalities and eligibility criteria for EVT in AIS across TSCs in South Korea. We observed substantial heterogeneity in both imaging protocols and eligibility criteria. Nearly all TSCs performed EVT in the late time windows, but this proportion declined substantially to less than half in the extended time windows. CT-based imaging protocol was the most commonly employed across all time periods, while the use of MR and perfusion imaging (CTP or MRP) increased progressively with longer time windows. Perfusion imaging-based eligibility criteria were the most frequently applied, with vendor-provided automated post-processing software being the predominant tool for perfusion image interpretation. However, TSCs without specific criteria for EVT still existed.

CT-based imaging protocols remain the predominant modality for EVT eligibility across all time windows due to their rapid acquisition, wide availability, minimal contraindications (e.g., pacemakers, patient agitation), and high sensitivity for hemorrhage detection, which together facilitate efficient workflow and timely intervention [11]. Combining non contrast CT (NCCT) with multiphase CTA enables rapid identification of occlusion sites and provides more accurate collateral flow assessment than single-phase CTA; indeed, approximately 70% of centers using CT-based protocols incorporated multiphase CTA. In the late time window, CTP is frequently integrated into CT-based protocols and can be acquired rapidly without significant delay[12]; accordingly, more than 80% of such centers included CTP as part of their imaging workflow.

Despite these advantages, CT-based protocols have limited sensitivity and inter-rater reliability for detecting early ischemic changes, and ASPECTS is optimized primarily for middle cerebral artery occlusion. More advanced imaging may therefore be warranted in later time windows [4]. In our study, MRI use increased notably in both late and extended time windows, either following CT or completely replacing it. This trend reflects a preference for DWI to assess the ischemic core, SWI or GRE for hemorrhagic lesions, and DWI–FLAIR mismatch to guide treatment in patients with stroke of unknown onset. Sequential CT-then-MR protocols may reflect a deliberate effort to minimize evaluation time while still leveraging the diagnostic strengths of DWI, hemorrhagic sequences, and FLAIR imaging. MR-based protocols have been associated with lower rates of futile recanalization and improved clinical outcomes compared with CT-based protocols [13]. However, sequential imaging inevitably prolongs the evaluation process and delays reperfusion therapy, potentially lowering the chance of achieving favorable outcomes [14, 15]. Further randomized trials directly comparing clinical outcomes between MR-based and CT-based protocols are warranted.

In our study, perfusion imaging has emerged as the primary tool for determining EVT eligibility in AIS beyond 6 h, with adoption rates increasing to 81.8% in late time windows and 100% in extended time windows. This trend, which has been particularly notable since 2016, may reflects the influence of the DAWN and DEFUSE-3 trials and facilitates the detection of small ischemic cores with large penumbral regions or distal vessel occlusions [16]. Perfusion imaging in Korea has been associated with increased EVT use in the late time window and a reduced risk of symptomatic intracerebral hemorrhage (ICH) in the early window [16]. However, interpretation of perfusion imaging can be challenging due to variable inter-rater agreement [17, 18]. Our survey revealed that advanced automated post-processing software was used in only 48.7% of the late time window. Although the use of RAPID software, employed in the pivotal trials, has increased since 2016, its application was only implemented in 13 centers (35.1%), predominantly in academic hospitals (12 centers, 92.3%). High licensing costs have led many centers in Korea to use alternative automated packages or visual inspection. Approximately 40% of TSCs now use vendor-provided perfusion assessment modules, while others employ third-party advanced post-processing platforms, such as Olea Sphere, Heuron, JLK AI suite, or TeraRecon, for quantitative analysis. Differences in thresholds across software packages can cause substantial variability in core and penumbra estimates, underscoring the need for standardized perfusion protocols and improved access to reliable, cost-effective automated software.

Traditional selection methods, such as ASPECTS, often combined with collateral status assessment, continue to play a critical role, particularly in settings where perfusion imaging is unavailable or impractical. Among the 12 physicians at 11 centers who did not use perfusion imaging, most (6 CT-ASPECTS, 1 DWI-ASPECTS) relied primarily on ASPECTS combined with collateral evaluation to determine EVT eligibility in the late time window. Outcomes in the late time window have been shown to

be comparable between patients selected using advanced perfusion imaging and those selected using CT-based methods such as ASPECTS [19, 20]. However, CT-based selection may overlook critical prognostic information uniquely provided by perfusion imaging [13, 21]. Indeed, three respondents using perfusion imaging highlighted its value in predicting procedural outcomes and guiding treatment decisions. Furthermore, because all centers performing EVT in the extended time window use perfusion imaging, omitting it could inadvertently exclude borderline patients who might benefit from EVT. Therefore, future patient-level analyses are warranted to clarify the optimal roles of perfusion and conventional imaging in patient selection.

Current Korean guidelines recommend that each center establishes and apply its own imaging modality to rapidly identify target mismatch in the late time window [7]. However, our study found that approximately 4% of respondents reported having no predefined eligibility criteria for EVT. Among TSCs using perfusion-based eligibility criteria, five relied solely on qualitative assessment without applying any quantitative thresholds, and roughly 25% of physicians applying perfusion imaging-based eligibility criteria had no pre-specified mismatch thresholds. In the absence of standardized eligibility criteria, patients who could benefit from EVT may be excluded, while those who are unlikely to benefit may undergo unnecessary treatment.

Our study has several limitations. First, selection bias may limit generalizability, as only 45 of 77 (58.4%) TSCs responded, most of which were tertiary hospitals, potentially underrepresenting practices at smaller or non-responding institutions. Second, the cross-sectional, self-reported design introduces information bias; protocol details were obtained through a single survey without external verification, leaving the data susceptible to recall and social desirability effects and raising the possibility that reported workflows may differ from routine bedside practice. Third, we did not capture patient-level and workflow metrics, such as door-to-puncture times, reperfusion success, functional outcomes, and cost, precluding any direct assessment of how imaging strategies affect clinical outcomes or resource utilization. Prospective, multicenter studies incorporating objective workflows and outcome data are needed to define optimal imaging pathways for EVT.

Compared with a 2020 study in South Korea, our findings demonstrate a significant shift toward greater use of advanced imaging and its integration into decision-making[6]; however, substantial variability in imaging and treatment protocols persists across centers. Standardization of imaging selection criteria could enhance consistency and improve outcomes across diverse healthcare settings.

Conclusions

This nationwide survey demonstrated substantial heterogeneity in the imaging protocols used to determine EVT eligibility in AIS patients presenting beyond 6 h at Korean thrombectomy-capable stroke centers. Most centers employed CT-based pathways supplemented by perfusion imaging, while others used sequential CT-then-MR or MR-based workflows depending on local resources. Perfusion-based criteria were the predominant method for patient selection in late and extended time windows, although ASPECTS-, collateral-based, and center-specific criteria were also used. These findings highlight the need for standardized and practical imaging strategies that can be consistently implemented across diverse clinical settings.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

J. Y., H.P. and Y.D.K. conceptualized and designed the study, drafted manuscript and acquired and analyzed the data. H.P., J.H.H, H.S.N, and Y.D.K. supervised and investigated this study. J.Y. prepared the figures and visualized the study. J. Y., H.P. and D.J.K. reviewed and edited the draft. Y.D.K. granted funding for this study.

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Data availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Institutional Review Board of Yonsei University College of Medicine (approval number: 4-2023-1025). Informed consent to participate was obtained electronically from all respondents prior to the initiation of the survey. The study was conducted in accordance with the ethical standards of the Institutional Review Board and with the 1964 Declaration of Helsinki and its later amendments.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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