Research Square

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Towards Dose Orientation Values for endovascular treatment of chronic subdural hematoma Analysis of the German Neurointerventional Database (DeGIR/DGNR) from 2018 to 2024

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Abstract

Purpose

A promising alternative to surgical treatment of chronic subdural hematoma (cSDH) has been endovascular embolization of the middle meningeal artery (MMAE). However, this treatment carries the downside of radiation exposure to the patients. To date, no explicit dose reference value (DRL) has been provided for this highly standardized procedure besides the overall valid DRL for intracranial aneurysm embolization (20,000 $cGycm^2$). This study aimed to address this issue by providing benchmarks to enable optimization of angiographic MMAE protocols in accordance with the ALARA-principle.

Methods

A retrospective analysis of data entries from the German DeGIR-QS Registry was conducted, covering the period from 2018 to 2024. The objective of this study was to determine a baseline value for MMAE. Additionally, the median values for the dose requirements and exposure times of the techniques used were analyzed, as were the trends in MMAE numbers over the years.

Results

A dose orientation value (DOV) was calculated at 11,830.5 $cGycm^2$. Liquid-based, as well as techniques labelled as “other methods,” surpassed this value in the 75th percentile, respectively. Particle-based MMAE were revealed to be the most frequently used technique with 44.60%, followed by liquids with 32.12%. Between years 2021 and 2024 the number of MMAE has increased by 436%.

Conclusion

MMAE provides a non-surgical alternative for treating cSDH. In recent years, the number of procedures performed has significantly increased. The DOV derived for MMAE shows that such statistical data should be explicitly evaluated for highly standardized procedures in order to provide grounds for optimization, which might otherwise go unrecognized.

Introduction

Chronic subdural hematoma (cSDH) is an increasingly common neurologic disease [1–5]. Standard treatment consists of surgical evacuation via burr holes or craniotomy with closed drainage systems [2, 4]. However, recurrence rates remain high (2–37%), with a one-year mortality rate of up to 32%, and overall failure rates between 5% and 50% due to persistence, progression, or recurrence [1, 2, 4–6]. Risk factors such as cerebral atrophy and anticoagulation further increase recurrence, particularly in elderly patients, who represent the majority of affected individuals [4, 7–9]. Reoperations are frequent and associated with complications and delayed rehabilitation [2]. Given these limitations, Middle Meningeal Artery Embolization (MMAE) has

emerged as an alternative treatment option over the past two decades [2, 3]. Recent randomized trials (EMBOLISE, MAGIC-MT, STEM) demonstrated improved outcomes compared to surgical drainage alone. Recurrence rates decreased to 4.6% for combined surgery and MMAE, and down to 6.8% for MMAE-only approaches, corresponding to an overall reduction of approximately 20% [2, 3, 10].

The use of MMAE is expected to increase. However, the introduction of endovascular neuroradiological treatments using time-resolved X-ray imaging entails radiation exposure. According to the ALARA principle, radiation dose should be minimized while maintaining sufficient image quality for safe catheter and micro-guidewire navigation. Dose reference levels (DRLs) serve as key tools for quality control. The German Federal Office for Radiation Protection (BfS) has established DRLs for intracranial endovascular procedures such as aneurysm embolization and stroke thrombectomy [11]. However, these procedures exhibit high variability in the following areas; dose area product (DAP) and exposure time (ET), which depends on lesion characteristics. The DRL of these procedures represent aggregated upper-percentile benchmarks across heterogeneous cases [12, 13]. In contrast, MMAE is a highly standardized procedure targeting the same vascular territory under similar conditions. Despite this, no specific DRL exist for MMAE, limiting the applicability of current benchmarks and preventing meaningful dose conformity assessments. To date, no multicenter percentile-based analysis of radiation exposure in MMAE has been performed. Therefore, MMAE procedures recorded in the DeGIR-QS registry, the largest database of radiological interventions in Germany, were analyzed for the years 2018–2024. Radiation dose and exposure time were evaluated annually and across the entire cohort to derive a DRL-like dose orientation value (DOV) and to assess the influence of technical factors. These results were compared with in-house data. This study provides the first multicenter based reference values for radiation exposure in endovascular cSDH treatment, allowing for practitioners to evaluate their procedures in accordance with the ALARA principle.

Material and Methods

DeGIR/DGNR Registry Data

All forms of nationally executed radiological interventions can be voluntarily documented in the registry of the German Society for Interventional Radiology and Minimally Invasive Therapy (DeGIR). The participation becomes mandatory once an institution seeks to be DeGIR/DGNR certificated or would like to obtain recognition as an interdisciplinary vascular center. Study information is therefore entered freely and without validation for plausibility in text fields via a web portal (Samedi GmbH, Berlin, Germany). The data provided by the DeGIR/DGNR is therefore multicentric. For our study all MMAE labeled entries for the years 2018 to 2024 were selected. Prior to data processing, erroneous data was removed. A filtration process was conducted using a Python-based in-house developed algorithm which, firstly, removed entries with missing dose and exposure time data. Then, records with similar entries for DAP and ET were removed, as this is regarded to be an insertion error. Third, entries with dose area products higher than 100,000 $cGycm^2$ and lower than 100 $cGycm^2$ were excluded, as these values are expected to be not accountable as realistic values. Finally, the remaining data was checked for missing used technique

entries. 2247 studies of the initial 2362 records were rendered feasible for further investigation after filtration (see Fig. 1). The filtration process follows the algorithm firstly introduced by Bärenfänger et. Al. [14]. However,

the last filtration step was excluded from our filtering. Bärenfänger et. Al. excluded records with DAP entries exceeding the documented ET in this step. We hypothesize that dominant amounts of series, digital substraction angiography (DSA) and 3D-acquisitions like cone beam CT (CBCT), compared to the amount of used fluoroscopic acquisition, can result in higher DAP than ET.

A retrospective analysis was conducted to assess the efficacy of dose-area product and exposure time for all technique variations included in the data. This was done for each year separately and once for all years combined to achieve insight towards the evolution of MMAE throughout the years. The subsequent data subsets were then evaluated based on the number of applications. Techniques with an overall application count lower than ten were rejected, as the finding is expected to be biased by a few outliners in such a study count. Ultimately, this rule was only applicable for single year analysis and explains the absence of the years 2019 and 2020 (see Fig. 1). Finally, techniques entered as “miscellaneous” and “multiple methods” were accumulated within an overall subset referred as “other methods”. The whole analysis was then repeated using our in-house MMAE studies to obtain comparable single site data.

Data Evaluation

Three technique-based data subsets were found and extracted from the filtered DeGIR Data registry. Additionally, one accumulated entry referred as “other methods” was obtained. For statistical analysis the median (50th percentile) value for DAP and ET was obtained as an overall impression for a cohorts performance in terms of dosage and time expenditure [12]. A year-wise comparison of dose-area products and exposure times for the four data subsets was performed to determine which technique is the most viable in terms of radiation protection and time efficiency and how this might have possibly changed over the years. The technique-based data subsets were then pooled year wise. This was done to obtain an overall impression of the dose and time efficiency course throughout the years.

Additionally, the 75th percentile of the pooled distribution was calculated as this is seen as a salient component in the definition of DRLs, thus giving a DRL like dose orientation value for MMAE [12]. This value was then compared to the valid German DRL for intracranial aneurysm therapy of 20,000 $cGycm^2$. Consecutively, the number of MMAE procedures performed each year was determined to gain insight into how strongly the numbers for this therapeutic approach in cSDH has increased since 2018.

The year and technique-based data subsets were then viewed as a whole to obtain one global dose orientation value for MMAE, which was then also compared to the national valid DRL for intracranial aneurysm therapy. In this overall assessment, we also compared dose data of in-house conducted MMAEs for the years 2023–2024 with the determined dose orientation value.

A Kruskall-Wallis test was used for significance testing of the year-wise based data subsets. This test evaluates more than two not normally distributed, independent data subsets. Its null hypothesis states that there is no discrepancy between the tested data sets [15]. For the DeGIR registry data, one data subset can be regarded as the median DAP or ET of the year wise technique differentiation. Therefore, this test is significantly significant if the tested data subsets inherit large differences in their median DAP or ET. Statistical significance was defined at $p < 0.05$.

Subsequently, Dunn's test was performed for results of the Kruskal-Wallis test that were rendered statistically significant. It can be regarded as a more specific approach as it compares the given groups (i.e. our techniques-based data subsets for a given year) pairwise and reveals which comparison was statistically significant. This test was chosen for post-hoc evaluation due to its non-parametric probability and the missing need for a particular data distribution. Its null hypothesis was that there is no difference between the tested data groups [16]. The threshold for significant results was set to $p < 0.05$. The statistical analysis algorithms as well as the test for the data's distribution (D'Agostino and Pearson's test [17, 18]) was performed with Python's scipy.stats library.

As mentioned before, these tests were only applicable for testing the created data subsets against each other. As a result, we used the Wilcoxon test to test the combined data against the German valid DRL of 20,000 cGycm^2, i.e. the 75th percentile of a German wide survey, for intracranial aneurysm therapy [11]. This test was chosen as a fitting test as it also is regarded as a non-parametric test for independent data samples that do not follow a normal distribution. Its null hypothesis is that there is no difference between the tested datasets. Usually, it compares the median values of two datasets. In our case we tested the 75th -percentile and the median value of the combined data versus the aforementioned DRL [19]. The significance level was set at $p < 0.05$.

Results

2247 records remained for analysis after filtration. For the first approach, an overview regarding the total number of applied techniques and their specific dose as well as time consumption in terms of DAP and ET for the years 2018-2024, was conducted. Our findings showed that particle-based approaches for MMAE are the most commonly used ones with approximately 44.60 % of all DeGIR registry reported records. Liquids follow in terms of application number at approximately 32.12%. "Other Methods" and coil usage revealed 20.43% and 2.85%, respectively. Comparing the median DAP and ET of the mentioned techniques, significant differences with $p = 1.76 \cdot 10^{-18}$ and $p = 5.83 \cdot 10^{-29}$ were obtained. Particle based MMAE approaches were rendered best performing regarding dose and time efficiency. However, coil-based MMAE performed similarly in terms of DAP, but with an increase in ET by 11.5 min (approximately 52.27%). The ET difference was found to be significant with $p = 3.04 \cdot 10^{-4}$. As the DAP was nearly the same for this technique comparison, no significance could be found (see Table 1 & Table 2).

An overall impression of MMAEs DAP expectation value as well as a dose orientation value was achieved by calculating the median and 75th percentile DAP from the aforementioned techniques. A significant difference with $p = 5.07 \cdot 10^{-305}$ was observed when comparing the DOV to the German valid DRL for intracranial aneurysm therapy. The DOV referred to 11,830.5 cGycm^2 which in turn is 40.85% lower than the DRL. Another interesting finding is that regardless of the significantly low DOV, liquid based and "other methods" MMAEs surpassed this value in the respective specific 75th-percentile (see Figure 2).

Table 1: Overview of the relative record number of the DeGIR records with the technique specific median and 75th DAP and ET for years 2018-2025. The values in red surpassed the DOV of 11,830.5 cGycm^2

Technique	relative recordnumber compared to a total of 2247 records	Median Dose-Area-Product [cGycm^2]	Median Exposure-Time [min]	75th Percentile
Particles	44.60%	5620.5	22	10194
Liquids	32.12%	7012	24	12500
Other Methods	20.43%	8753	36	14364
Coils	2.85%	5992,5	33.5	7623

Table 2: P-Values of the post-hoc Dunn test. It shows whether technique yield significant differences towards another. Values in green are rendered significant while the red ones show insignificant findings.

Dunn Test p-Values for inter-technique Significance DAP				
	Particle	**Liquids**	**Other Methods**	**Coils**
Particles	N/A	$1.01 \bullet 10^{-7}$	$4.19 \bullet 10^{-17}$	1
Liquids	$1.01 \bullet 10^{-7}$	N/A	$2.59 \bullet 10^{-3}$	0.05
Other Methods	$4.19 \bullet 10^{-17}$	$2.59 \bullet 10^{-3}$	N/A	$1.95 \bullet 10^{-4}$
Coils	1	0.05	$1.95 \bullet 10^{-4}$	N/A
Dunn Test p-values for inter-technique Significance ET				
	Particle	**Liquids**	**Other Methods**	**Coils**
Particles	N/A	$1.33 \bullet 10^{-4}$	$6.38 \bullet 10^{-29}$	$3.04 \bullet 10^{-4}$
Liquids	$1.33 \bullet 10^{-4}$	N/A	$3.18 \bullet 10^{-12}$	0.09
Other Methods	$6.38 \bullet 10^{-29}$	$3.18 \bullet 10^{-12}$	N/A	1
Coils	$3.04 \bullet 10^{-4}$	0.09	1	N/A

History of MMAE for years 2018-2024

An analysis of the annual application numbers, considering the development of dose consumption and exposure time, showed that despite an exponential increase in the number of MMAE applications, the associated DAP and ET consumption initially decreased. A total of 245 MMAEs in year 2021 increased to 575 within two years. This accounts for a relative increase of procedures performed by approximately 135%. At the same time median dose usage decreased from 8,126 cGycm^2 to 5,630 cGycm^2, which refers to a relative reduction by approximately 30.72%. ET at the other hand was rather static. The median was reduced from 28 minutes to 24 minutes.
Nevertheless, in the following year from 2023 to 2024 a rise in both ET and DAP was observed resulting in median values of 26 minutes and 6,670 cGycm^2 (ca. +8.3% and +18.5%), respectively. Additionally, the number of procedures performed nearly doubled within this year from 575 to 1,069 (+85.9%), ultimately

resulting in a total rise of MMAE procedures of 436% from 2021 to 2024.
Further investigation regarding the year specific influence of different techniques showed that MMAEs' cumulative DAP expenditure was mostly influenced by liquid and particle based approaches (see Figure 3 & Table 3).

Technique	Years							
	2021		2022		2023		2024	
	Number	DAP [cGycm^2]	Number	DAP [cGycm^2]	Number	DAP [cGycm^2]	Number	DAP [cGycm^2]
Particles	129	6,459	193	6,426	272	5,260	408	5,270
Liquids	41	10,870	79	8,575	193	4,873	409	7,380
Other Methods	73	10,562	67	6,178	91	7,862	228	8,987
Coil	N/A	N/A	19	6,260	19	556	24	5,729

Table 3: Absolute Numbers of median DAP and record count throughout the years.

Benchmarking in-House data

The aforementioned analysis revealed a DOV of 11,830 cGycm^2 for MMAE. This value was used to obtain insight towards the dose effectiveness of in-house performed MMAE for the years 2023-2024, with a total of 43 studies included in analysis. All 43 studies were performed using liquids. Median DAP and the 75th percentile, i.e. the in-house DOV, was 11,664 cGycm^2 and 16,622 cGycm^2, respectively. Comparison of these results with the DeGIR registry data showed an increase in dose usage by approximately 79% and 41% in terms of median and 75th percentile (DOV). As previously mentioned, the in-house dose data was derived by only liquid based MMAE therapy. In order to address the technique-induced bias of the overall median and DOV, a comparison was conducted using only DeGIR records that were performed using the same technique. However, the difference in the outcome was rendered insignificant, as median DAP and the 75th percentile yielded 7012 cGycm^2 and 12,500 cGycm^2, which in terms were only approximately 7% and 6% higher than the overall DeGIR median and DOV (see Table 4 & Figure 4).

Table 4: Absolute and relative values of the in-house dose values and those found in the DeGIR registry for MMAE. The relative values were calculated based on the entries in "DeGIR ALL DATA," as these can be considered the most suitable reference values due to their minimal bias. Consequently, benchmarking in-house dose values with values derived more or less globally can reveal potential for optimization, whereas the exclusive use of in-house DOVs can lead to the opposite conclusion.

Dataset	Values					
	Absolute			Relative [%]		
	Number	Median [cGycm^2]	75th Percentile/DOV [cGycm^2]	Number	Median	75th Percentile/DOV
DeGIR all data	2,247	6,532	11,830	100	100	100
DeGIR only Liquids	722	7,012	12,500	32.13	107.35	105.66
In-House only liquids	43	11,664	16,622	1.91	178.57	140.51

Discussion

In this study, records from the DeGIR registry regarding embolization of the middle meningeal artery (MMA) were analyzed to evaluate median dose-area product (DAP) and exposure time (ET) [28]. The primary objective was to establish multi-center dose orientation values (DOVs) against which medical institutions can benchmark their local procedures [12]. This benchmarking is of growing clinical relevance, given the rapid increase in MMA embolization procedures in recent years [12]. As demonstrated in our results, there was an approximate 86% increase in recorded case numbers from 2023 to 2024 alone. Consequently, MMA embolization is poised to become an increasingly important complementary or standalone endovascular approach to the conventional surgical management of chronic subdural hematoma (cSDH) [2, 3, 10].

While endovascular treatment significantly reduces procedural complication rates compared to open surgery, this clinical benefit comes at the cost of exposing the patient to ionizing radiation [2]. The International Commission on Radiological Protection (ICRP) defines the nominal risk coefficient for radiation-induced cancer mortality as 5% per Sievert (Sv) of effective dose [20]. Applying the conversion factor of 0.00058 mSv per cGycm² for head X-ray examinations established by Wall et al. [21], the median DAP and the proposed DOV for MMA embolization correspond to an estimated effective dose of 3.79 mSv (attributable mortality risk of 1 in 5,277 examinations) and 6.86 mSv (attributable mortality risk of 1 in 2,915 examinations), respectively.

Because radiation-induced solid tumors typically exhibit a latency period spanning several decades, this oncogenic risk is less clinically significant in the typical cSDH population, where the majority of patients are older than 65 years [22]. However, younger patients can also develop cSDH, albeit with lower probability [4, 7–9]. For this younger subgroup, cumulative radiation risks must be weighed with extraordinary care, making strict adherence to the ALARA (As Low As Reasonably Achievable) principle mandatory [23].

Dose reference levels serve as a fundamental tool for quality control and dose optimization [12]. Standard quality assurance requires testing local median doses against national DRLs; if these benchmarks are exceeded, institutions must investigate and optimize their imaging parameters [12, 24, 25]. Currently, no specific DRL exists for MMA embolization, leaving the national DRL for the "embolization of intracranial aneurysms" (20,000 cGycm²) as the closest legally valid benchmark in Germany [11]. This aneurysm

benchmark is 69.06% higher than our derived DOV (11,830.5 cGycm²). Relying on the aneurysm DRL would completely obscure the need for local optimization. The high value of the aneurysm DRL stems from the fact that intracranial aneurysm treatments are highly heterogeneous, non-standardized, and heavily dependent on complex lesion anatomy and varying device configurations, such as coils, flow diverters, or stent-assisted techniques [13]. In contrast, MMA embolization is a highly standardized intervention targeting a predictable vascular territory under similar conditions, rendering the aneurysm DRL entirely unsuitable for accurate benchmarking.

Whether an institution complies with the ALARA principle depends on the equipment used, procedural scope, and the operator's experience—particularly regarding techniques that influence radiation exposure. Thus, single center data can always yield dose orientation values, but without showing optimization potential due to its bias. This becomes clearer by the exemplary benchmark of our in-house MMAE dose statistics. This limitation is clearly illustrated by our in-house data. An exclusive internal comparison of our local median values with our internal DOV would erroneously suggest that our protocols require no adjustment. However, benchmarking against the multi-center DeGIR data reveals a different reality: our local DOV (16,622 cGycm²) is 40.51% higher than the DeGIR benchmark, and our internal median DAP nearly matches the multi-center 75th percentile. Without an MMA-embolization-specific multi-center DOV, the clinical necessity to investigate and optimize our internal protocols would have remained unrecognized.

We identified two primary factors driving our elevated local dose. First, our institutional preference relies entirely on liquid embolic agents, which our registry analysis proved to be the technique associated with the highest radiation exposure (see Fig. 3). Unlike particle embolization, which can often be delivered in a single or rapid deployment, liquid embolic agents require slow, controlled, continuous injection. This process necessitates extensive fluoroscopic monitoring and frequent digital subtraction angiography (DSA) or roadmapping series to evaluate embolic cast formation, track vascular distribution, and minimize the risk of dangerous reflux. Consequently, liquid agents significantly increase both DAP and exposure times compared to particles. (see Table 2 & Fig. 2).

Second, our institute's academic teaching profile plays a major role. Because MMA embolization is highly standardized and relatively forgiving compared to complex interventions like arteriovenous malformation (AVM) embolization, it may serve as an entry-level training procedure for fellows learning liquid embolic techniques. Less experienced operators naturally require more prolonged fluoroscopy and additional imaging runs to confirm microcatheter position and procedural success, inherently driving up the radiation dose.

The longitudinal registry data shows that particle-based approaches remain the most common (44.60%), whereas coil-based techniques are the least utilized (2.85%). Currently, there is no clinical consensus on the single optimal embolic agent, as each method presents unique advantages and technical trade-offs [27]. Particles and liquids both successfully occlude the distal microvasculature supplying the cSDH membrane, but both carry a risk of non-target embolization via dangerous anastomoses [26, 27]. Liquid embolic agents additionally carry the risk of microcatheter entrapment during the solidification process. Furthermore, standard clinical practice often requires sequential, selective embolization of both the frontal and parietal branches of the MMA. With liquid agents, this frequently demands microcatheter exchange and repeat

catheterization, resulting in cumulative fluoroscopic time and higher radiation doses than particle-based approaches.

Conversely, distal coil occlusion of the MMA carries the risk that the coils alone will not penetrate or occlude the microvascular network driving the cSDH membrane to a satisfactory extent [27], which might explain why coil-only approaches represent only 2.85% of the DeGIR cohort. While newer specialized devices aim to overcome this limitation by facilitating distal segment deployment prior to packing [27], their broader impact on radiation dose profiles remains to be validated. Under the ALARA framework, if clinical equivalence between agents is established, operators should preferentially opt for the lower-dose approach, which our data identifies as particle-based embolization.

Conclusion

Endovascular treatment of chronic subdural hematomas (cSDH) via middle meningeal artery embolization (MMAE) has gained significant importance in recent years. It has thus established itself as an alternative to conventional surgical therapy, whether as an adjunct or as a standalone treatment approach. Although patients undergoing MMAE are exposed to radiation, no dose reference value tailored to this highly standardized therapy has been established to date. To address this issue and enable a benchmark of institutional scanning protocols—and ultimately ensure compliance with the ALARA principle—a dose orientation value of 11,830.5 cGycm² was calculated. Provided that clinical circumstances and treatment success do not preclude adapting the treatment approach to the most dose-efficient technique, the values specified in this study can be used as a guideline or as a justification in the case of exceeding this value.

Declarations

Author Contribution

C.S. wrote the main manuscript text, created the tables, the first figure and calculated the relative values.C.F. coded the used python script, created all other figures and rose the statistic values.R.S, E.F. and P.S. reviewed the manuscript in terms of content and speech.

Data Availability

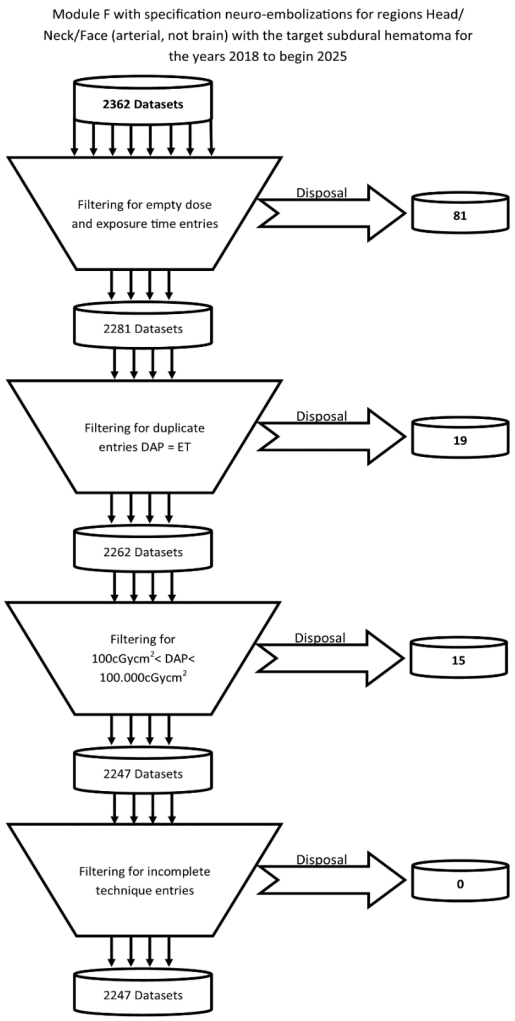
Available with restricted access:The data used for this study are available from German Neurointerventional Database (DeGIR/DGNR). Restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. The data are, however, available upon request and with the permission of German Neurointerventional Database (DeGIR/DGNR).

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Figures



DEGIR/DGNR technique entries				
Year	Particles n = 1002	Liquids n = 722	Coils n = 62	Other Methods n = 459
2021	129	41	N/A	73
2022	193	79	19	67
2023	272	193	19	91
2024	408	409	24	228

Figure 1

Scheme of the used filtration algorithm. 2362 records were reported for years 2018-2025. After applying all filtration steps checking for validity, 2247 records remained for further analysis. Particle and liquid based approaches appeared to be dominant in application numbers. Data differentiation for years 2019 and 2020 was rendered insufficient, as the overall reported Study count within the DeGIR registry was smaller than 10.

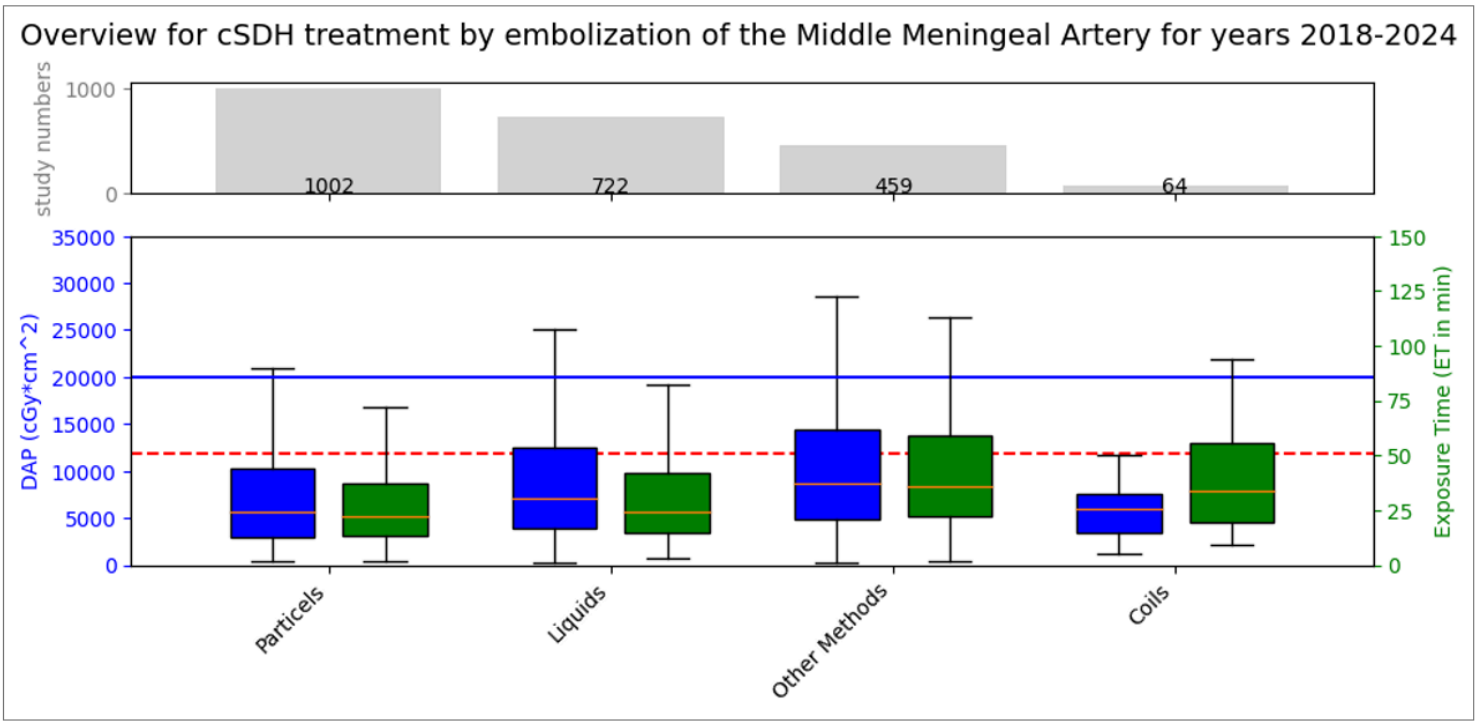


Figure 2

Overview of the filtered DeGir record data statistic distribution separated by technique. The red dashed line indicates the derived dose orientation value. The blue line shows the national valid DRL for intracranial aneurysm therapy.

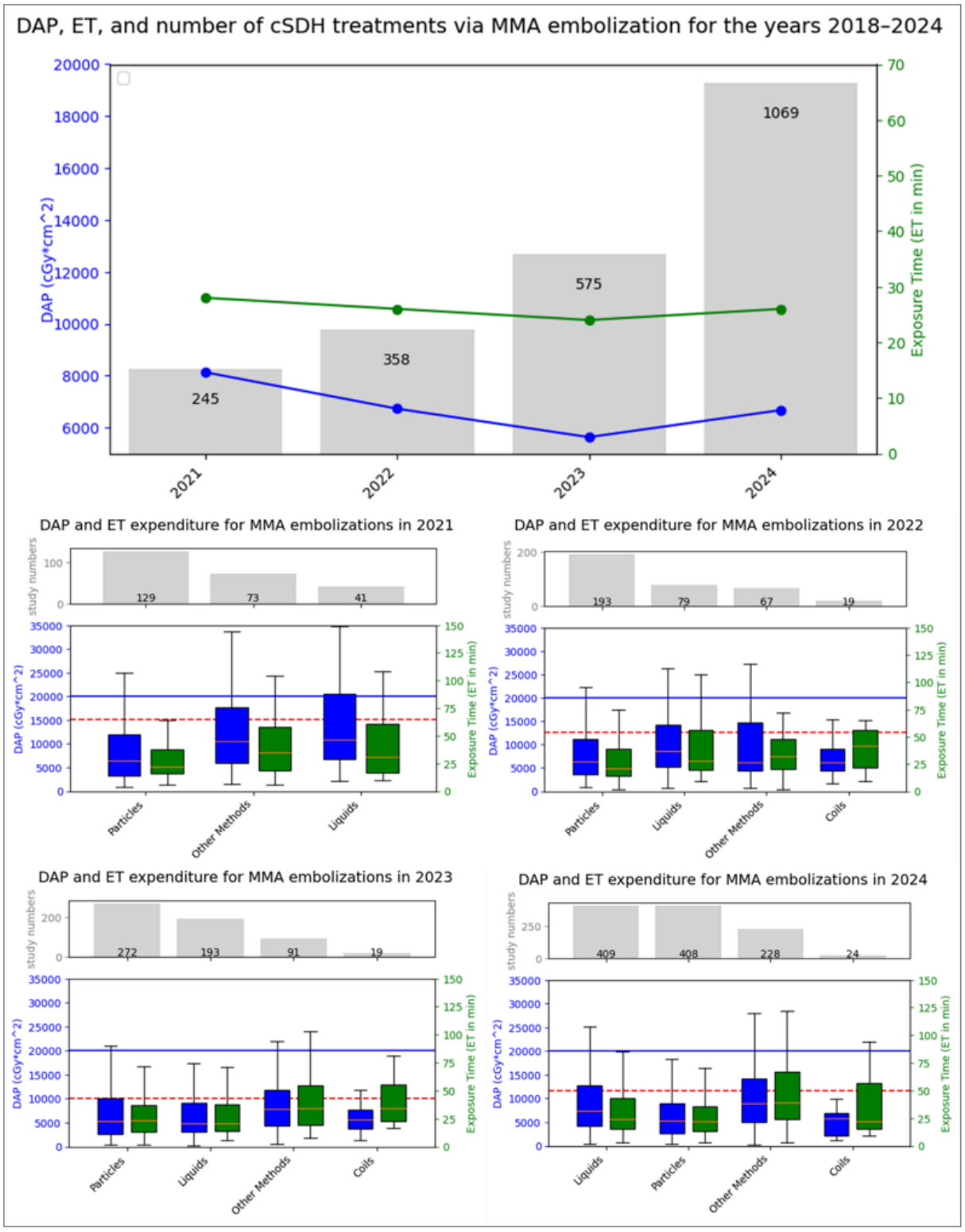


Figure 3

Evolution of MMAE for cSDH treatment over the years 2018-2025. Records starting in year 2021 were rendered feasible for evaluation. Thus, no plots for years 2018, 2019 and 2020 are shown. At the top the cumulative course of rising case numbers, median Dap and ET are shown. For further insight towards the influence of the course, technique differentiated analysis was conducted for every year.

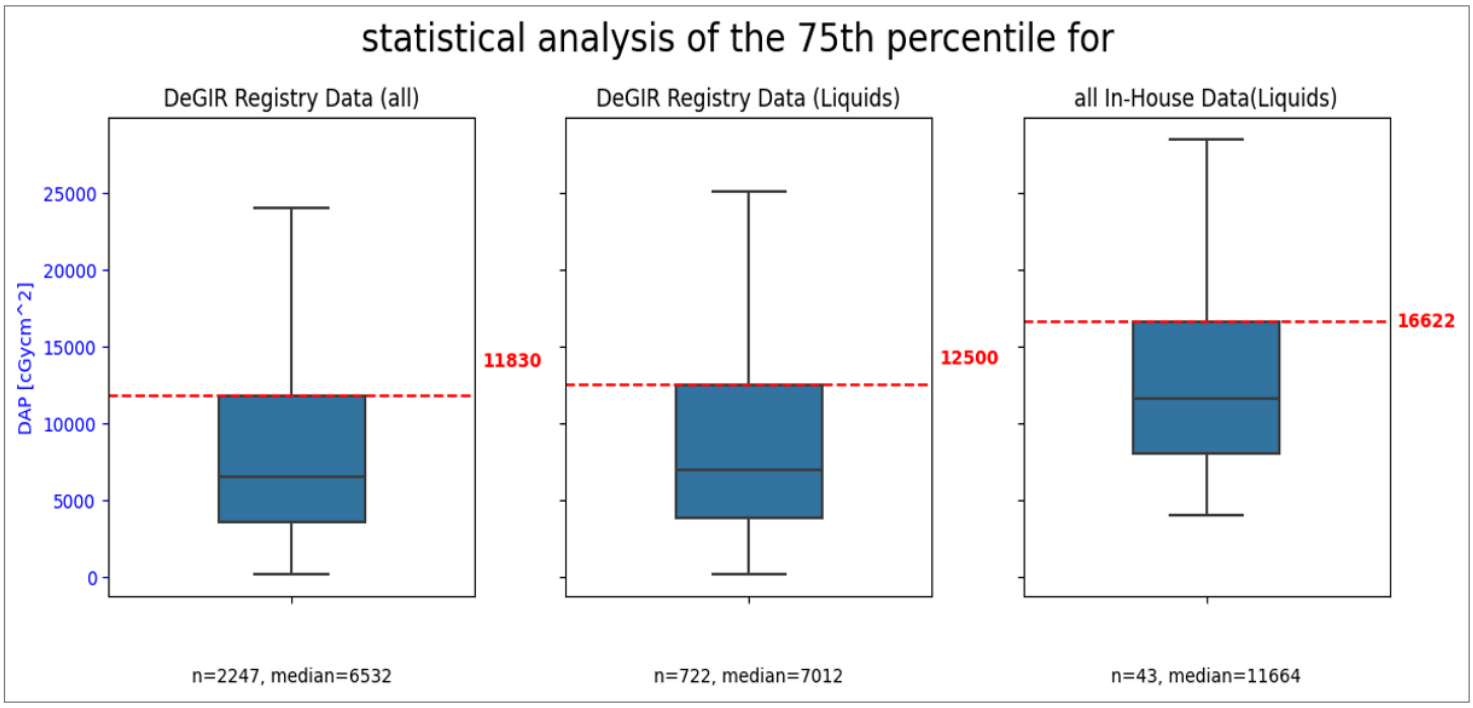


Figure 4

Plot of the values mentioned in Table 4