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Temporal Muscle and Stroke—A Narrative Review on Current Meaning and Clinical Applications of Temporal Muscle Thickness, Area, and Volume

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Abstract:

Background: Evaluating muscle mass and function among stroke patients is important. However, evaluating muscle volume and function is not easy due to the disturbance of consciousness and paresis. Temporal muscle thickness (TMT) has been introduced as a novel surrogate marker for muscle mass, function, and nutritional status. We herein performed a narrative literature review on temporal muscle and stroke to understand the current meaning of the TMT in the clinical stroke practice. Methods: The search was performed in PubMed, last updated in October 2021. Report on temporal muscle morphomics and stroke-related diseases or clinical entities were collected. Results: Four studies reported on TMT and subarachnoid hemorrhage, 2 intracerebral hemorrhage, 2 ischemic stroke, 2 standard TMT values, and 2 nutritional status. TMT was reported as a prognostic factor for several diseases, surrogate markers for skeletal muscle mass, and an indicator of nutritional status. Computed tomography, magnetic resonance imaging, and ultrasonography were used to measure TMT. Conclusions: TMT is gradually used as a prognostic factor of stroke or surrogate marker for skeletal muscle mass and nutritional status. Establishing standard methods to measure TMT and large prospective studies to investigate the further relationship between TMT and diseases are needed.

Keywords: frailty; muscle volume; nutritional status; prognostic factor; sarcopenia; skeletal muscle mass; stroke; temporal muscle thickness.

1. Introduction

Stroke is a widely known cause of disability [1]. Stroke also increases the risk of skeletal muscle loss [2], sarcopenia, which contributes to further disability related to stroke [3]. Furthermore, pre-stroke sarcopenia is also associated with poor functional outcomes [4,5]. Therefore, evaluating muscle mass and function among stroke patients is important [6,7], and aggressive nutrition therapy [8–10] or rehabilitation [11] is applicable for those with stroke as well as high risks for muscle loss.

Measuring skeletal muscle mass and function is an evolving parameter for the clinical evaluation of physiological conditions [12]. The golden standard to evaluate muscle loss, sarcopenia, is muscle function test, such as gait speed test and grip strength test, according to the European Working Group on Sarcopenia in Older People (EWGSOP), EWGSOP2, and the Asian Working Group for Sarcopenia (AGWS) [13,14]. However, measuring muscle function like grip strength and gait speed measurement sometimes cannot be performed because stroke patients often have a disturbance of consciousness, sedation, rest due to surgical treatment, and paresis. Therefore, an alternative method to evaluate muscle mass and function is needed.

Recently, temporal muscle thickness (TMT) on the computed tomography (CT) image or magnetic resonance images (MRI) has been introduced as a novel surrogate marker with which to measure the muscle mass [15], function [16], and nutritional status [17,18]. CT and MRI are routinely performed for stroke patients, and TMT measurement is easy. Therefore, TMT is attractive as the alternative method to evaluate muscle mass and function for stroke patients. The purpose of this narrative literature review, we herein present, is to investigate the reports on TMT and stroke and to understand the current meaning of the TMT in the clinical stroke practice. In addition to TMT [19,20], we also examined temporal muscle area (TMA) [19,21,22] and temporal muscle volume (TMV) [9] as the similar things of TMT.

2. Materials and Methods

Studies regarding TMT and stroke were examined. The search was performed in PubMed, last updated in October 2021, using the terms "stroke" OR "intracerebral hemorrhage (ICH)" OR "subarachnoid hemorrhage (SAH)" OR "cerebral infarction" OR "rehabilitation" OR "sarcopenia" OR "frailty" OR "nutrition" AND "temporal muscle thickness". The PubMed search resulted in a total of 73 articles. We systematically read through the abstracts of all original articles available in English. We included the studies on the association between stroke and TMT with a sample size of around 50 cases and appropriate statistical analyses. We also checked through the lists of the references to complete our collection of studies. All the authors verified the correct transcription of the data to our manuscript. Finally, we included 8 studies related to stroke in our review.

3. Results

Four studies reported the association between TMT and SAH [9,19,21,22], 2 ICH [23,24], 2 ischemic stroke [25,26]. The other 4 studies described the standard TMT values [16,27] and the relationship between TMT and nutritional status [17,18].

3.1. Temporal muscel and SAH

Katsuki first reported TMT as a prognostic factor for SAH outcome in 2019, investigating 49 SAH patients over 75 y.o. who were treated by clipping with craniotomy [19]. The TMT was measured on CT image on admission, using Aquilion ONE (Canon Medical Systems Corporation, Tochigi, Japan) with 0.5 × 0.5 x 1.0 mm voxels. The slice thickness was reconstructed to 5 mm. The window width was adjusted to 300, and the window level was adjusted to 20. The TMT was measured bilaterally perpendicular to the long axis of the temporal muscle at the slice 5 mm above the orbital roof using SYNAPSE V 4.1.5 imaging software (Fujifilm Medical, Tokyo, Japan). Then, the averages of the left and right of the TMTs were used. This method to measure TMT on CT was first defined. They performed univariate analysis regarding TMT and functional outcome at 6 months The study was preliminary, but the study first suggested that larger TMT was related to favorable outcomes among elderly SAH.

They next investigated the relationship between temporal muscle and Hunt and Kosnik Grade on admission and functional outcome at 6 months [21]. They examined 298 all age-group patients, and all the patients were treated by endovascular coiling. They revealed that Hunt and Kosnik grade on admission and functional outcome were related to TMT and TMA. TMA was measured manually by tracing the outline of the temporal muscle on the same CT slice as that used for measuring the TMT. Notably, this study suggests that TMT and TMA are related to both the severity of SAH and functional outcome regardless of age, not only for the elderly.

They then investigated 127 SAH patients under 75 y.o. who were treated by clipping [22]. They examined the cut-off values for the functional outcomes. Receiver operating

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characteristic analysis found that the threshold of TMT was 4.9 mm in women and 6.7 mm in men, and that of TMA was 193 mm^2 in women and 333 mm^2 in men, which were the cut-off values for the functional outcomes among SAH patients under 75 y.o.

Onodera [9] examined TMV using volume rendering software (Ziostation 2 version 2.9.5.1, Ziosoft, Tokyo) because TMT might be less reproducible. They investigated 60 SAH patients and measured TMV on the CT images at admission and 2 weeks after aneurysm treatment. Patients whose TMV had decreased by ≥20% were classified into the "atrophy group," whereas those whose TMV had decreased by <20% were classified into the "maintenance group." Their study showed that the food intake score and the functional outcome were significantly more positive in the TMV maintenance group than the TMV atrophy group. Therefore, they suggested that the importance of early high-protein administration to maintain TMV in the acute term (Table 1).

Table 1. Previous reports on the association between temporal muscle and SAH

Author	Year	Number of cases	Abstract
Katsuki [19]	2019	49	Large TMT was related to favorable outcomes among elderly SAH.
Katsuki [21]	2020	298	TMT and TMA were related to Hunt and Kosnik Grade and functional outcome at 6 months after endovascular coiling regardless of age.
Katsuki [22]	2021	127	The threshold of TMT was 4.9 mm in women and 6.7 mm in men, and that of TMA was 193 mm^2 in women and 333 mm^2 in men, which were the cut-off values for the functional outcomes at 6 months among SAH patients under 75 y.o.
Onodera [9]	2021	60	The food intake score and the functional outcome at discharge were significantly more positive in the TMV maintenance group than the TMV atrophy group after SAH.

Abbreviations: SAH: subarachnoid hemorrhage; TMA: temporal muscle area, TMT: temporal muscle thickness, TMV: temporal muscle volume

3.2. Temporal muscle and ICH

Katsuki examined 75 ICH patients treated by endoscopic hematoma removal and investigated the factors related to the functional outcome [23]. They revealed that lower total protein level was related to the poor outcome at 6 months. In addition, they mentioned TMA as an indicator of nutrition, but TMA itself was not significantly related to the outcome ($p = 0.08$). However, they suggested that low nutritional status, indicated by lower total protein level and low TMA altogether, seemed to be associated with poor outcomes.

Gomes examined 24 post-hemorrhagic stroke patients in the chronic stage and tested the bite force and TMT [24]. Maximum molar bite force was verified using a digital dynamometer. TMT was measured using ultrasound images obtained at rest and during maximal voluntary contraction of the masseter and temporalis muscles. The TMT at the unaffected side was larger than the affected side. This study first focused on the functional and morphological changes in the stomatognathic system after a hemorrhagic stroke. The clinical meaning of these changes would be investigated (Table 2).

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Table 2. Previous reports on the association between temporal muscle and ICH

Author	Year	Number of cases	Abstract
Katsuki [23]	2019	75	Low nutritional status, indicated by low total protein level and low TMA altogether, seemed to be associated with the poor functional outcomes at 6 months after endoscopic hematoma removal.
Gomes [24]	2021	24	TMT at the unaffected side was larger than the affected side after a hemorrhagic stroke.

Abbreviations: ICH; intracerebral hemorrhage, TMA: temporal muscle area, TMT: temporal muscle thickness

3.3 Temporal muscle and stroke

Sakai [25] investigated 70 acute cerebral infarction patients' TMT on the T2-weight MR image and functional oral intake scales. They revealed that TMT was a significant explanator of dysphagia severity following acute ischemic stroke, along with age and the National Institute of Health Stroke Scale score. The measuring method of TMT using T2-weighted images was similar to the previous report from Furtner using T1-weighted images [28]. They first reported the association between TMT and ischemic stroke-related dysphagia in the acute term.

Nozoe [26] examined 289 acute elderly stroke patients and investigated the TMT on CT image as an indicator of sarcopenia risk and its relationship with the functional outcome at 3 months. They found that sarcopenia risk was independently associated with TMT in older patients with acute stroke. However, TMT was not independently related to the functional outcome (Table 3).

Table 3. Previous reports on the association between temporal muscle and stroke

Author	Year	Number of cases	Abstract
Sakai [25]	2021	70	TMT was a significant explanator of dysphagia severity following acute ischemic stroke.
Nozoe [26]	2021	289	Sarcopenia risk was independently associated with TMT in older patients with acute stroke, but TMT was not independently related to the functional outcome.

Abbreviations: TMT: temporal muscle thickness

3.4 Standard values of TMT

Steindl [16] investigated 624 normal collective cohort to establish standard reference values of TMT on the T1-weighted image. TMT was measured on isovoxel ($1 \times 1 \times 1$ mm^3) T1-weighted MR images perpendicularly to the long axis of the temporal muscle on an axial plane, which was oriented parallel to the anterior commissure-posterior commissure line. They also examined 422 healthy volunteers and 130 cases as prospective validation cohort and found that TMT and grip strength were correlated. This was the first report to validate the relationship between the TMT and grip strength, namely muscle function, prospectively.

Katsuki [27] investigated 360 Japanese individuals' brain check-up database obtained by MRI. They measured TMT in the same way previously reported [16] to obtain the standard values of TMT among Japanese individuals. They compared their result to Steindl's results to know the racial difference, but the background of the participants so

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differed. They did not perform any muscle function test, so further investigation is needed (Table 4).

Table 4. TMT and nutritional status

Author	Year	Number of cases	Abstract
Steindl [16]	2020	1175	Standard values of TMT were investigated, and TMT and grip strength were correlated.
Katsuki [27]	2021	360	Standard values of TMT were investigated among Japanese individuals who underwent brain check-ups.

Abbreviations: TMT: temporal muscle thickness

3.5 TMT and nutritional status

Hasegawa [18] investigated 73 elderly individuals to measure their TMT using ultrasonography and nutritional status assessed with anthropometric measurements and laboratory tests. TMT was strongly correlated with calf circumference and arm muscle circumference. However, there were no strong correlations with serum protein levels nor fat mass evaluated as triceps skinfold thickness. They also examined the reliability to measure TMT using ultrasonography, and the inter-rater reliability was 0.99.

They also performed a prospective study [17]. The study aimed to examine whether a change in TMT evaluated by the ultrasonography was directly correlated with energy adequacy and to determine the cut-off value of a change in TMT to detect energy inadequacy. They investigated 48 bedridden elderly patients and revealed that percentage change in TMT was significantly correlated with energy adequacy. They suggested that the assessment of TMT changes could be helpful for performing better nutritional therapy (Table 5).

Table 5. TMT and nutritional status

Author	Year	Number of cases	Abstract
Hasegawa [18]	2019	73	TMT was strongly correlated with calf circumference and arm muscle circumference. However, there were no strong correlations with serum protein levels nor fat mass evaluated as triceps skinfold thickness.
Hasegawa [17]	2021	48	TMT changes were directly correlated with energy adequacy in bedridden older adults.

4. Discussion

We herein reviewed the reports on TMT and stroke. TMT is useful as a prognostic marker for SAH, ICH, and dysphagia after stroke. It also indicates nutritional status and risk of sarcopenia. As the number of reports on TMT and stroke has been increasing rapidly in recent years, we believe that TMT is one of the crucial factors in clinical practice. In addition to this review, we discuss the TMT measurement method and TMT use in other neurosurgical practices.

4.1 TMT measurement method

The standard TMT measurement method has not been established. The old report used volume rendering software [29,30], and Onodera also used a similar approach [9] to measure TMV, not TMT. Then, Furtner established TMT measurement using T1-weighted MR images. They measured TMT perpendicular to the long axis of the temporal muscle at the level of the orbital roof [12,15,16,31,32]. This method is widely used, but low accessibility to MRI in routine work is a problem. Sakai [25] used T2-weight MR images, not T1-weighted images. The difference between the T1- and T2-weighted images should be discussed. Katsuki first defined TMT and TMA on CT images [19]. CT is more accessible rather than MRI, so TMT on CT seems better for routine clinical work. Hasegawa used ultrasonography (M-Turbo; SonoSite, Bothell, WA, USA) to measure TMT at 4 cm from the eyelid and 2 cm above the reference line that was the orbitomeatal line [18]. Ultrasonography is not so reproducible, but their study reported that TMT measurement by ultrasonography is reliable.

As described above, there are some ways to measure temporal muscle morphomics, including TMT, TMA, and TMV. Easiness and high reproducibility are needed to establish the standard method. Further study on the measurement method is desired.

4.2 Temporal muscle in other neurosurgical practice

The first report on the temporal muscle as a prognostic factor in neurosurgical practice was to evaluate the operative risk in nonsyndromic craniosynostosis in 2013 [30]. The authors used volume rendering software to assess the temporal fat pad. From this report, there have been several papers on the temporalis muscle and prognosis, especially in brain tumors. There are several reports on the overall survival and temporal muscle in glioblastoma [32–39], metastatic brain tumor [28,40,41], and primary central nervous system lymphoma[31,42]. Like those on TMT and stroke, all of these reports have in common that the temporal muscle was used to indicate nutritional status and skeletal muscle mass volume. The larger the temporal muscle, the better the outcome, probably due to good nutritional status and more skeletal muscle mass.

4.3 Limitations

As described above, TMT is now attractive, and many studies have been performed, but some issues should be addressed. First, most of the studies were retrospective, so further prospective study is needed. Second, the sample sizes were small, so studies with large sample sizes are desired. Third, the TMT measurement method was not established, and several ways can be used, like MRI, CT, and ultrasonography. The standard approach to measuring TMT is needed. Fourth, the direct mechanism of why large temporal muscle relates to favorable prognosis has not been clarified. The true mechanism between TMT and outcomes should be discussed from several perspectives, such as rehabilitation, nutrition, frailty, deglutition, or basic medicine. Some of the problems may be resolved as TMT measurements will be routinely taken with tracking time-course changes.

5. Conclusions

TMT seems a useful surrogate marker for skeletal muscle volume and function, and would be a potential prognostic factor. The research on the association between stroke and TMT is now increasing. Further research is needed to establish the usefulness of TMT.

6. Patents

Not applicable.

Supplementary Materials: Not applicable.

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