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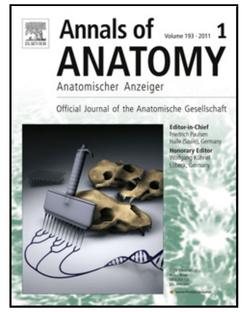

Title: THE MORPHOLOGICAL VARIATIONS OF THE LATERAL PTERYGOID MUSCLE: A SYSTEMATIC REVIEW

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PII: S0940-9602(18)30136-5
DOI: https://doi.org/10.1016/j.aanat.2018.10.006
Reference: AANAT 51317

To appear in:

Received date: 19-2-2018
Revised date: 19-9-2018
Accepted date: 10-10-2018

Please cite this article as: Stöckle, Matthias, Fanghänel, Jochen, Knüttel, Helge, Alamanos, Christos, Behr, Michael, THE MORPHOLOGICAL VARIATIONS OF THE LATERAL PTERYGOID MUSCLE: A SYSTEMATIC REVIEW.Annals of Anatomy https://doi.org/10.1016/j.aanat.2018.10.006

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THE MORPHOLOGICAL VARIATIONS OF THE LATERAL PTERYGOID MUSCLE: A SYSTEMATIC REVIEW

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Query 2: see Email - Attachments. You will have all figures and tables in an editable word-file.

Query 3: Citation for Figures 4-6 is given on page 5 under "anatomical method". We made these Figures while examining and preparating the hemisected head.

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Summary

Background: The lateral pterygoid muscle (LPM) has been described in many anatomical and functional studies. The morphology of the LPM is still under debate because of its deep location in the infratemporal fossa and the difficulties to approach this area with different anatomical methods. Although it has been generally accepted that this muscle is mainly composed of two separate parts, other forms have been described in the past.

Objectives: To conduct a systematic literature review regarding the anatomy and variations of the LPM.

Methods: We included studies published in English, German or French employing anatomical and imaging methods or a combination of the two methods. The cadavers used in the dissections had to be human and without any pathological alterations. Studies were only included when focusing on the anatomy of the LPM or its morphological variations or when taking the frequency of variations into account. . We searched 26 biomedical databases including MEDLINE, EMBASE, BIOSIS

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Previews and Science Citation Index Expanded (part of Web of Science) through October 2014.

The review was followed by the dissection of a hemisected head in two different planes that showed a three-headed version of the LPM.

Results: We identified 4279 records (2200 after deduplication) in the databases searches plus 17 articles from manual searches. 81 studies out of these articles were included in this review. 69 articles used anatomical methods, 5 imaging methods and 7 studies a combination of the two methods. 11 studies took into account that the LPM may have variations and also considered the relative frequency of each variation. The frequency of one-headed LPMs ranged between 7.7% and 26.7%, of two-headed LPMs between 61.4% and 91.1% and of three-headed LPMs between 4.0% and 35.0%.

Discussion: In anatomical studies, different preparation techniques seem to be the main reason for diverging results.

Keywords:

1. Lateral pterygoid muscle
2. Number of heads
3. Origin/Insertion
4. Sytematic literature review

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Introduction

The lateral pterygoid muscle (LPM) plays an important role in the orofacial system. This muscle is active during protrusion, abduction and mediotrusion and particularly during exact mandibular movements such as singing, clenching and speaking (Coskun et al., 2005; Schumacher, 1997; Tillmann, 2003).The LPM is the only masticatory muscle with horizontally arranged fibres. Understanding its function or malfunction requires detailed knowledge of the anatomy and the possible variations of this muscle.

The LPM is located deeply in the infratemporal fossa, and the inaccessibility of this area and its surrounding tissue makes anatomical dissections very difficult (El Haddioui et al., 2005). The fact that the LPM consists of two separate heads has been widely accepted, but other forms do exist. Such variations are termed types, but the terminology differs between authors (Abe et al., 1993; Antonopoulou et al., 2013). In the literature, the anatomy of the LPM has also been described as one-headed (Naohara, 1989; Abe et al., 1993; Foucart et al., 1998), two-headed (Choukas and Sicher, 1960; Sümnig et al., 1991; Moritz and Ewers, 1989) and three-headed (Troiano, 1967; Birou et al., 1991; Fujita et al., 2001).

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The aim of this study was to provide a systematic review of the literature on the number and function of the heads of the LPM.

Material and methods

Eligibility criteria: The LPM can be examined by means of different methods: Anatomical methods (conventional dissection of cadavers), functional methods (electromyographical examination) and imaging methods (magnetic resonance tomography (MRT) and computer tomography (CT)). The different methods can also be combined. Functional studies were excluded from this review because they do not provide any new anatomical knowledge. The cadavers used in the dissections had to be human and without any pathological alterations. Studies were only when focusing on the anatomy of the LPM or its morphological variations or when taking the frequency of variations into account. We only considered studies published in English, German or French (Table I).

Information sources: The search was conducted on October 9, 2014, using all 26 medical databases (Table II) hosted at the German Institute of Medical Documentation and Information (DIMDI) at that time (a total of 141,732,059 records). This included MEDLINE, EMBASE, BIOSIS Previews and Science Citation Index Expanded (part of Web of Science). Database coverage was from the inception up to the date of searching.

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Search: A single search concept "lateral pterygoid muscle" was identified in the research question. We selected appropriate thesaurus terms for the databases and a broad range of synonyms to create a highly sensitive search strategy that was run on all selected databases simultaneously. In the database search we did not include any language restrictions. For records from BIOSIS Previews we employed the controlled term "primates" as a filter to exclude articles solely on non-primate species. The full search strategy in the DIMDI ClassicSearch query language is given in Table III.

In addition to the electronical search we conducted a manual search of the bibliographies of all articles selected for full-text analysis.

Data processing: Deduplication of records stemming from different databases was done by an automatic process of the database host DIMDI. Export of records from the host was on a pay-per-use basis. Therefore, in order to save costs as a first step just the titles and accession numbers of all records after deduplication were exported from the host. These records were transformed into an Excel file which was used to screen the records by title. Then full bibliographic records incl. abstracts of all hits found to be possibly relevant were exported from the host. These records were transferred into reference management software for subsequent screening by abstract and final eligibility assessment by full-text.

<u>Anatomical method:</u>

Anatomical dissection was conducted using a hemisected head (fixation: alcohol, formaldehyde, softener and rose oil). First, the upper and lower venters of the LPM were accessed by means of the conventional lateral method. To be able to evaluate the third head of the LPM, we had to change the examination level to get a different view of the muscle by preparation through the middle cranial fossa. This way, we achieved a superior view of the LPM, a method that was first used by Pinto (1962)

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when examining the temporomandibular joint (TMJ) and the middle ear. We had to enlarge this method of access to anterior to be able to examine the LPM in total.

Results

The electronic search yielded 4279 hits (see search step 26 in Table III). The elimination of duplicates (search steps 27 and 28 in Table III) reduced this to 2200 records for manual screening of the titles. Only Articles in English, German and French were accepted at this stage. The remaining 185 records were further screened by abstract. This resulted in 119 articles from the database search for further full-text analysis.

The manual search yielded 17 additional records, increasing the number of articles for full-text revision to 136. According to the inclusion and exclusion criteria, 81 papers were included in this review. A schematic overview of the information flow through this systematic review is provided in Fig.1.

Of the 81 studies included in this study, 69 used anatomical methods, 5 imaging methods and 7 studies a combination of the two methods.

The majority of papers (70 out of 81) did not report on the relative frequency of LPM variations. 60 articles described a two-headed version of the LPM, 5 a three-headed version, and 3 publications a one-headed LPM. Moritz (1986) and Antonopoulou et al. (2013) described an LPM consisting of two and three parts (Fig. 2).

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11 studies took into account that the LPM may have variations and also considered the relative frequency of each variation (Sugisaki et al., 1986; Naohara et al., 1989; Wilkinson and Chang, 1989; Abe et al., 1993; Petermann, 1994; Foucart et al., 1998; Fujita et al., 2001; Akita et al., 2003; Pompei et al., 2009; Kilic et al., 2010, Abe et al., 2011). Sugisaki et al. (1986), Naohara et al. (1989), Abe et al. (1993), Foucart et al. (1998) showed that LPMs may have one, two or three heads. Wilkinson (1989), Petermann (1994), Fujita et al. (2001), Akita et al. und Kiliç et al. (2010) described the two-headed and three-headed versions. Pompei et al. (2009) examined the frequency of the three-headed version by means of an MRT, and Abe et al. (2011) described LPMs with one and two heads (Fig. 3).

Altogether, the authors of these 11 studies investigated 521 subjects or cadavers. 343 TMJs were investigated by means of anatomical methods and 178 with imaging methods such as MRT. The relative frequency of the one-headed version of the LPM ranges between 7.7% - 26.7%, the two-headed version between 61.4% - 91.1% and the three-headed version between 4.0% - 35.0%.

<u>Anatomical examination:</u>

When examining and preparing the hemisected head, we found similar results to those detected by Troiano (1967). Removal of the fascia surrounding the LPM showed a clear division of the upper head in a medial (LPMM) and a lateral (LPML) part.

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Discussion

Publications on anatomical methods and the preparation of human cadavers provide detailed information on the structure to be examined. Descriptions of the three-dimensional proportions between the LPM and the surrounding structures, such as bone, nerves and vessels, are also widely available.

Preparation of the LPM is very difficult due to its deep location in the infratemporal fossa and the fact that the muscle is covered and surrounded by tissues, which makes access to the muscle itself difficult.

A stereomicroscope is often used to examine small structures and to trace the origin or insertion of muscle fibres (Abe et al., 1993; Sümnig et al., 163). However, important parts of muscles, nerves or vessels may be damaged by inappropriate preparation (Poland, 1980). Abe et al. (1993) argued that the method of dissection for examining the LPM is negligible, whereas Haddioui et al. (2005) reported that conventional preparation techniques are limited when used to examine the LPM in its deep location.

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However, the experience of the author or the anatomical dissector is of great importance. Troiano (1967) and Poland (1980) showed that careless dissection may damage the structure to be examined, which, in the worst case, could lead to misinterpretations of the anatomy of the LPM. Parts of the LPM or its surrounding structures may be accidentally removed if the dissector is unaware of the correct anatomy of the infratemporal fossa and its surrounding structures. Therefore, presence of a two-headed instead of a three-headed LPM may be assumed. A similar problem occurred during our anatomical examination. When only the lateral dissection method is applied, the anatomy of the LPM may be misinterpreted, because the LPMM is often covered by the more laterally positioned LPMS. This situation could be another reason for incorrect interpretations of the anatomy of the LPM in the past.

Troiano (1967) discovered a third medial head at the same level of the LPMS. During our own dissection, we detected the same form of a third head that appears to be covered by the LPMS when viewed from a lateral or superior position. Therefore, a multi-level approach seems to be indicated for the correct examination of the LPM. When only the lateral approach is applied, the possible existence of a third part of the LPM may be overlooked. Furthermore, anatomical and imaging methods can be combined to reduce misinterpretations of the anatomy of the LPM.

The one-headed LPM was mentioned in 68 publications, but 60 out of 68 articles (88.2%) identified an LPM with two heads, 5 (7.4%) an LPM with three heads and 3 (4.4%) an LPM with one head. These results should be considered carefully, because some of the studies mentioned above examined the region of the TMJ but were not focussed on the LPM and its variations.

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In contrast, the results published in the following studies were significant (Sugisaki et al., 1986; Naohara et al., 1989; Wilkinson and Chang, 1989; Abe et al., 1993; Petermann, 1994; Foucart et al., 1998; Fujita et al., 2001; Akita et al., 2003; Pompei et al., 2009; Kilic et al., 2010, Abe et al., 2011), because some of these authors examined their subjects from different planes and perspectives. The authors depicted the frequency of each anatomical variation of the LPM. In these 11 articles, 521 subjects were examined: 343 by means of anatomical methods and 178 with imaging methods. The frequency of one-headed LPMs ranged between 7.7% and 26.7%, of two-headed LPMs between 61.4% and 91.1% and of three-headed LPMs between 4.0% and 35.0%. These data can be considered significant, because the studies focused on the LPM and its variations.

Imaging methods are particularly suitable for examining and depicting the soft tissues of diseased TMJs (Westesson, 1993; Taskaya-Yilmaz et al., 2005; Pompei et al., 2009). By now, MRT has replaced arthroscopy and CT in the diagnosis of TMJ diseases (Westesson, 1993). The big advantage of MRT is the lack of emission of any harmful X-rays. Sagittal pictures of the TMJ are very useful for interpreting the LPM, although misinterpretations are possible. For instance, the tendon of the LPM may be misinterpreted as a part of the discus (Crowley et al., 1996).

Pompei et al. (2009) discovered a three-headed LPM in 20.22% of investigated cases, while several other authors argue that the LPM has two heads (Katzberg et al., 1985; Adachi et al., 1985; Quémar et al.,1993; Pedullà et al., 2009; Mazza et al., 2009; D'Ippolito et al., 2010).

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According to Pompei et al. (2009), the complete amount of muscle fibres of the LPMM inserts into the discus. The course of these muscle fibres indicates that they could have an important function in stabilising the discus. Furthermore, Pompei et al. (2009) assumed that the third head of the LPM may play a role in displaced or dysfunctional joint discs.

MRT plays an important role in clinical routine, because anatomic proportions, pathological alterations and the surrounding soft tissues can be very well depicted without any harmful invasive intervention. In contrast to anatomical methods, the surrounding tissue of the examined area does not have to be dissected and can consequently not be damaged by manual preparation. Imaging methods in combination with anatomical studies are useful to reduce misinterpretation and help to arrange an anatomical examination.

Conclusions

A multi-level approach to examining the LPM or to dissecting the TMJ with its adjacent structures en-bloc seems to be indicated to avoid confusion. One possible multi-level approach could be combining the superior and the lateral approach. Combining different methods such as anatomical methods with imaging methods is also helpful. In future, these improvements may minimise the differences in results obtained by different authors and could at best lead to a more homogenous description of the LPM.

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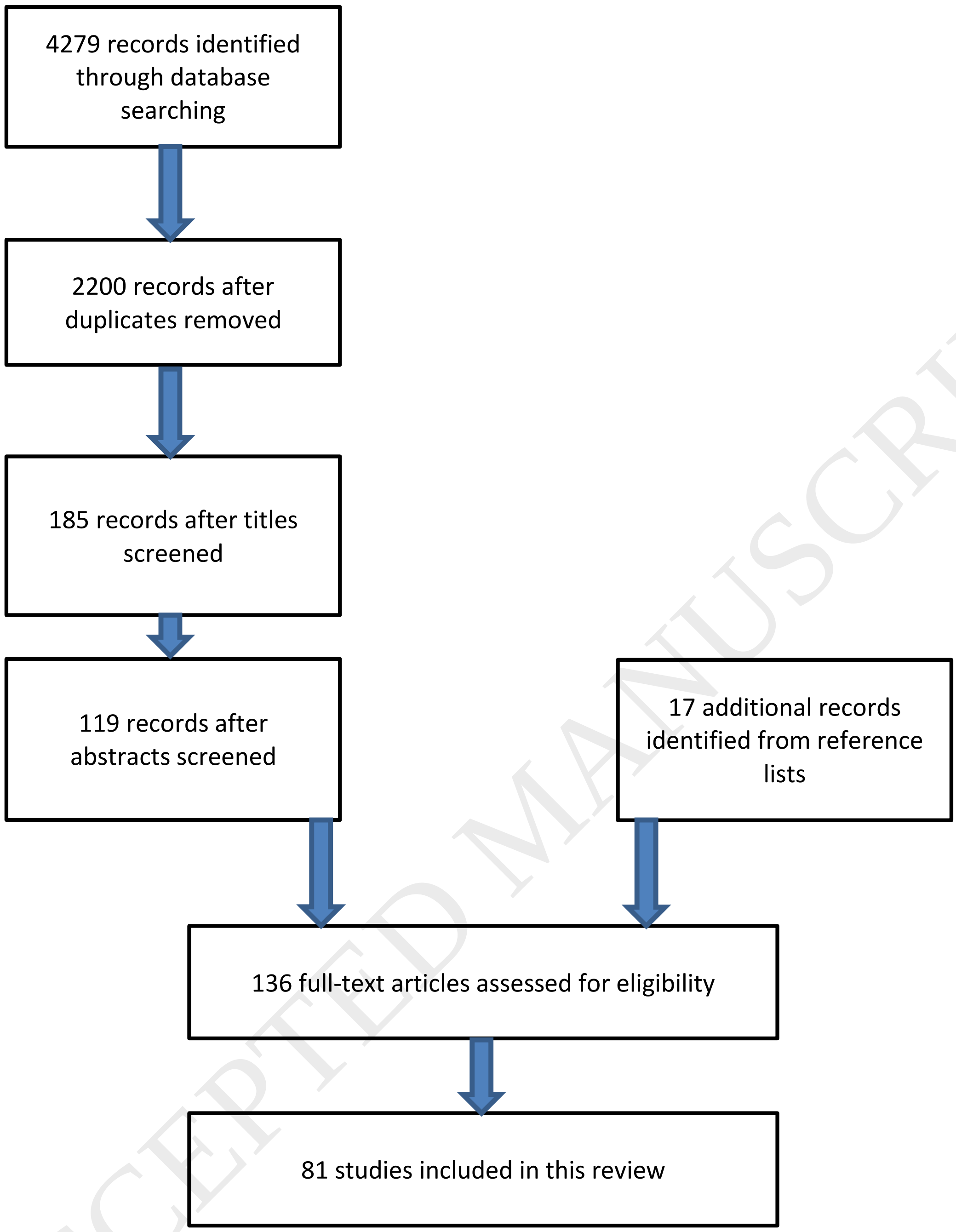

Fig. 1. Schematic diagram of the information flow.

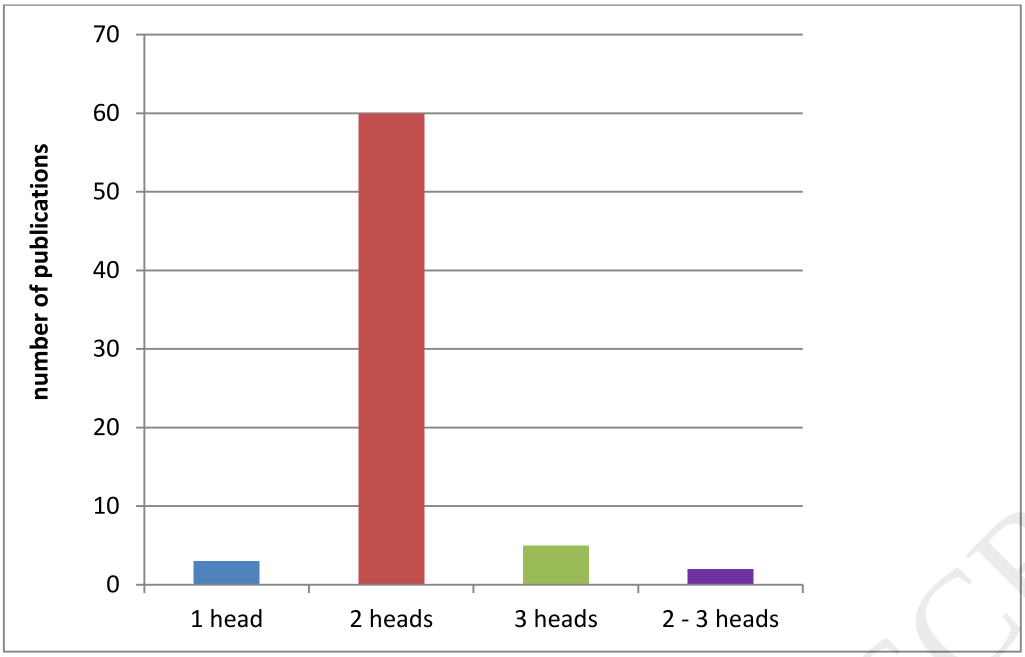

Fig. 2. Number of heads of the LPM in anatomical and imaging studies from 1931 to 2013.

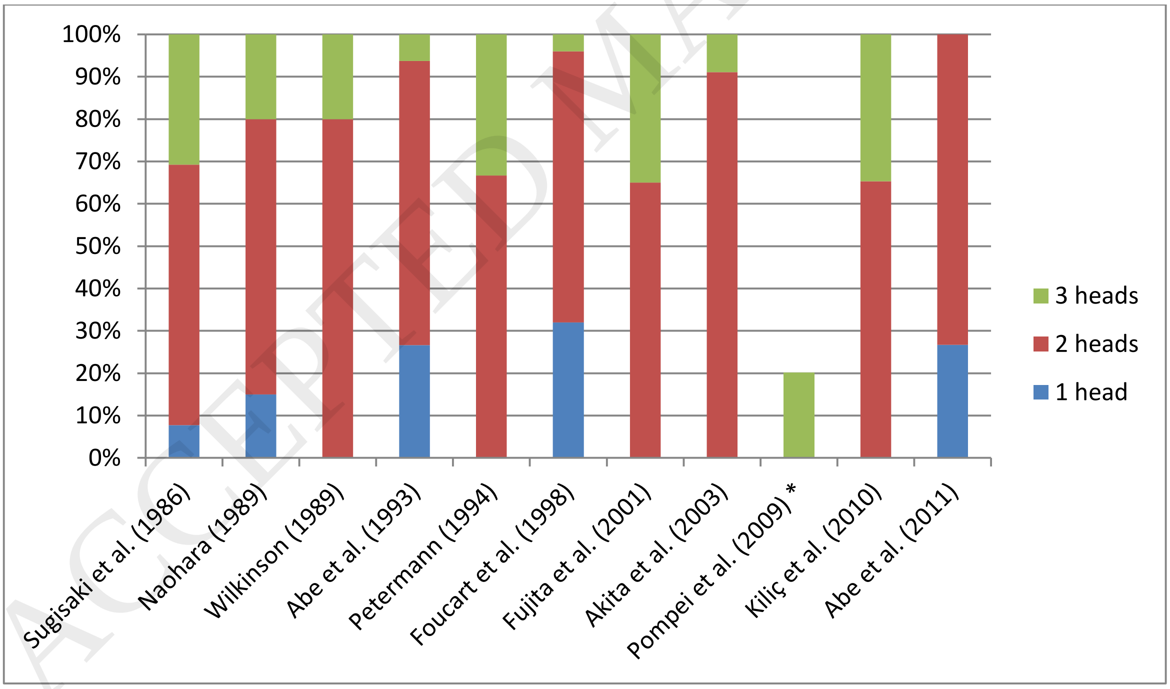

Fig. 3. Relative frequencies of the variations of the LPM in 11 publications with anatomical and imaging methods from 1986 to 2011. *Pompei et al. (2009) examined only the occurrence of the three-headed type with a MRT; thus, data of the other variations were missing.

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Fig. 4. Depiction of the LPM by means of the conventional lateral dissection method. The arcus zygomaticus has been removed for a clear view of the LPM.
The Separation between the upper and lower head of the LPM is clearly visible.
(Subject provided by Professor Fanghänel, University Greifswald/Regensburg).
MT: Musculus temporalis
AZ: Arcus zygomaticus
MPLS: Musculus pterygoideus lateralis, pars superior
MPLI: Musculus pterygoideus lateralis, pars inferior
NA: Nervus alveolaris inferior

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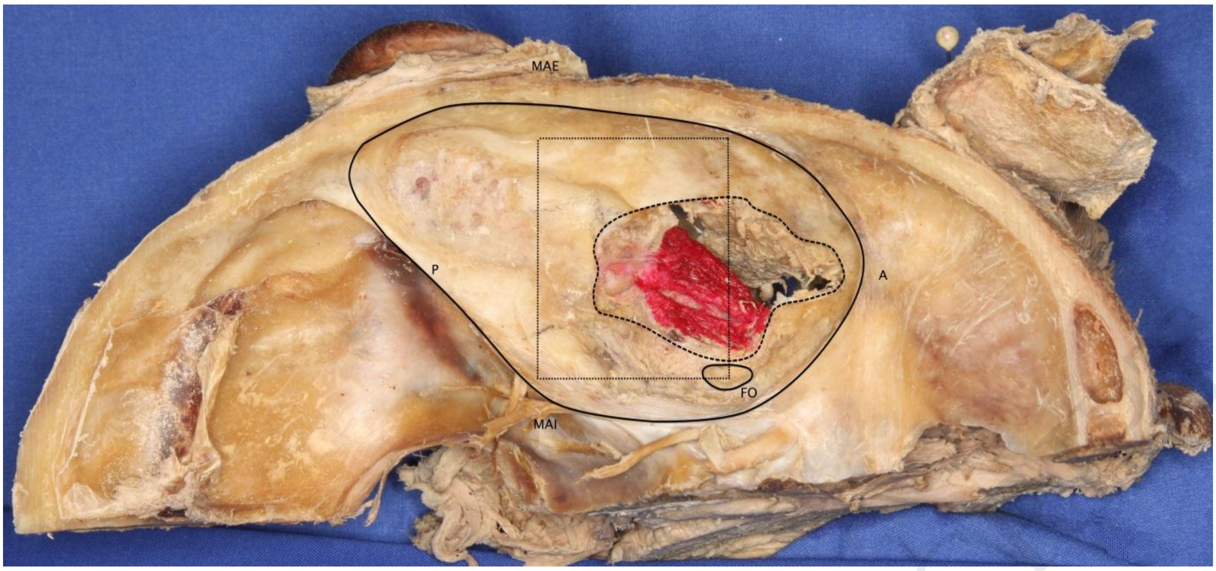

Fig. 5. Superior approach to the LPM through the medial cranial fossa according to Pinto (1962). The separated upper head of the LPM is clearly visible (subject provided by Professor Fanghänel, University Greifswald/Regensburg).
Dotted line: Approach according to Pinto (1962)
Dashed line: Extended anterior approach to trace the fibres of the LPM to their origin.
Continuous line: Medial cranial fossa
MAE: Meatus acusticus externus
MAI: Meatus acusticus internus
FO: Foramen ovale
A: Anterior, P: Posterior

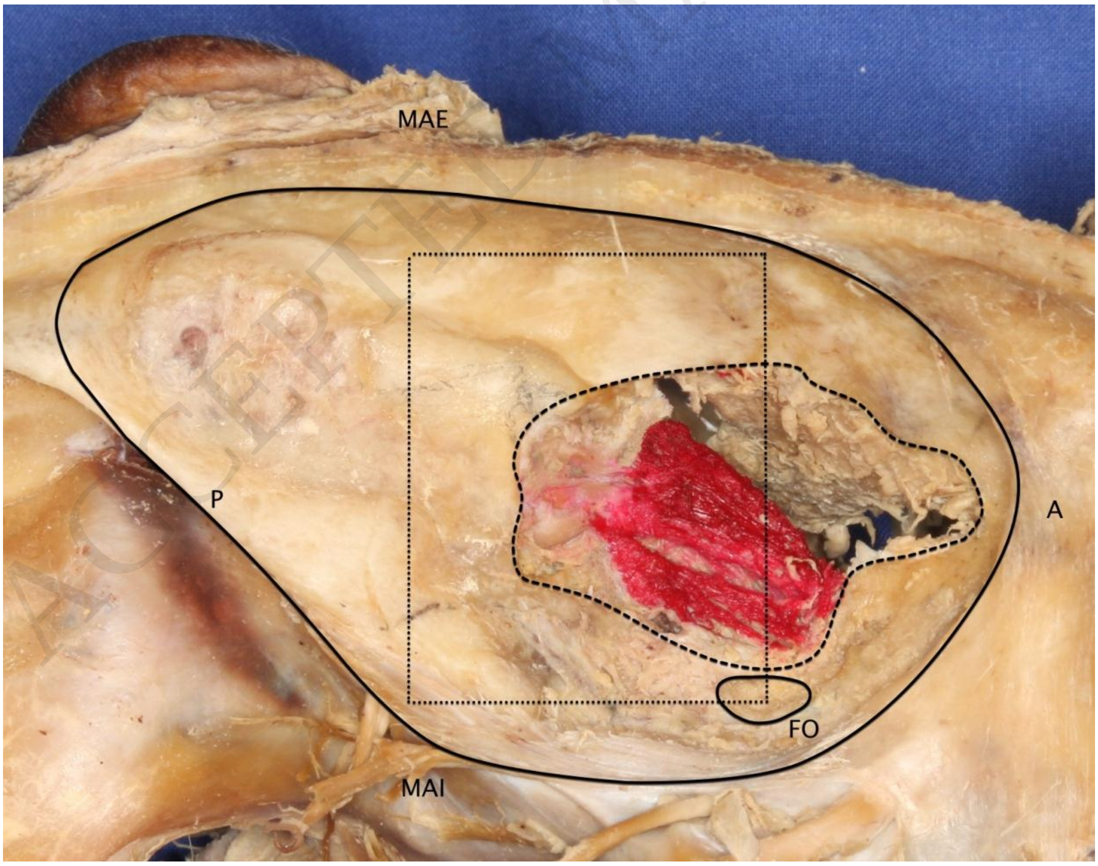

Fig. 6. Magnification of Fig. 5

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Table I. Inclusion and exclusion criteria.

Inclusion criteria

- Studies with their focus on the topography of the TMJ with its surrounding tissues and particularly the anatomy of the LPM.
- Publications with their own anatomical results, no reviews.
- Accepted methods: Anatomical dissection, imaging methods (CT and MRT) and the combination of both.

Exclusion criteria

- Animal studies.
- Human cadavers with pathological alterations.
- Publication languages other than English, German and French.

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Table II. Databases used in the search process.

Code	Database name
ZT00	AnimAlt-ZEBET
CC00	CCMED
CCTR93	Cochrane Central Register of Controlled Trials
CDSR93	Cochrane Database of Systematic Reviews
DAHTA	DAHTA-Datenbank
CDAR94	Database of Abstracts of Reviews of Effects
AR96	Deutsches Aerzteblatt
GA03	gms
GM03	gms Meetings
INAHTA	Health Technology Assessment Database
MK77	MEDIKAT
NHSEED	NHS Economic Evaluation Database
ED93	ETHMED
ME60	MEDLINE
CV72	CAB Abstracts
CB85	AMED
AZ72	GLOBAL Health
IA70	IPA
BA70	BIOSIS Previews
EM47	EMBASE
DH64	Derwent Drug Backfile
EA08	EMBASE Alert
DD83	Derwent Drug File
II78	ISTPB + ISTP/ISSHP
IS74	SciSearch (Science Citation Index Expanded)
BA26	BIOSIS Previews

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Table III. Electronic search strategy in the DIMDI ClassicSearch query language**.** From left to right: numbers of search statement, numbers of hits and search expressions.

No	Hits	Search expression
C= 1	141732059	ZT00; CC00; CCTR93; CDSR93; DAHTA; CDAR94; AR96; GA03; GM03; INAHTA; MK77; NHSEED; ED93; ME60; CV72; CB85; AZ72; IA70; BA70; EM47; DH64; EA08; DD83; II78; IS74; BA26
S= 2	7817	CT = PTERYGOID MUSCLES
3	6989	2 AND BASE=EM47
4	1961	3 AND (ANATOMY;HISTOLOGY;INNERVATION;INSERTION;ORIGIN)
5	406	4 AND LATERAL?
6	929	3 AND LATERAL?
7	828	2 NOT 3
8	1234	7;5
9	43	MUSCULUS PTERYGOIDEUS LATERALIS
10	75	(M;MUSC?) PTERYGOIDEUS LATERALIS
11	1904	LATERAL PTERYGOID MUSCLE#
12	0	LATERAL? FLUGELMUSK?
13	2	LATERAL? FLUEGELMUSK?
14	122	PTERYGOID?, # # # LATERALIS. AND MUSC?
15	2402	PTERYGOID?, # # # LATERAL. AND MUSC?
16	379	(M;MUSC?), # # # PTERYGOIDEUS.
17	4018	(M;MUSC?), # # # PTERYGOID.
18	34	(PTERYGOID;PTERYGOIDEUS), # # # MYOTOMY.
19	40	PTERYGOID, # # # ELECTROMYO?.
20	0	PTERYGOIDEUS, # # # ELECTROMYO?.
21	3	PTERYGOID, # # # MECHANOMYO?.
22	0	PTERYGOIDEUS, # # # MECHANOMYO?.
23	4687	8 - 22
24	524	23 AND BASE=(BA26;BA70) AND CT D PRIMATES
25	3755	23 NOT BASE=(BA26;BA70)
26	4279	25;24
27	3691	26 NOT SU=MEDLINE
28	2200	check duplicates: unique in s=27

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Table IV. Breakdown of search results by database before deduplication.

Database code	Database name	Number of hits
CCOO	CCMED	1
CCTR93	Cochrane Central Register of Controlled Trials	19
CDAR94	Database of Abstracts of Reviews of Effects	1
GA03	Gms	5
GM03	Gms Meetings	6
MK77	MEDIKAT	6
ME60	MEDLINE	1376
CV72	CAB Abstracts	38
CB85	AMED	8
AZ72	GLOBAL Health	14
BA70	BIOSIS Previews	502
EM47	EMBASE	1417
EA08	EMBASE Alert	3
DD83	Derwent Drug File	5
II78	ISTPB + ISTP/ISSHP	36
IS74	SciSearch	820
BA26	BIOSIS Previews	22
	Total	**4279**

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Table V. Results of the main eleven articles in this research concerning methods, number of specimens/patients, age distribution, ethnic origin, gender distribution and correlations between these attributes. a) the detailed age range distribution is available in Fujita et al. (2001), page 561.

Author	Methods	Number of specimens/patients	Age	Ethnic origin	Gender distribution	Correlations
Sugisaki et al. (1986)	anatomic	14	n.a.	n.a.	n.a.	n.a.
Naohara (1989)	anatomic	25	n.a.	n.a.	n.a.	n.a.
Wilkinson (1989)	anatomic	5	n.a.	n.a.	n.a.	n.a.
Abe et al. (1993)	anatomic	79	n.a.	n.a.	n.a.	n.a.
Petermann (1994)	anatomic	42	n.a.	n.a.	n.a.	n.a.
Foucart et al. (1998)	anatomic	22	60 - 101	n.a.	5 female, 6 male	n.a.
Fujita et al. (2001)	anatomic	20	a)	n.a.	15 female, 5 male	n.a.
Akita et al. (2003)	anatomic	45	n.a.	n.a.	11 female, 14 male	n.a.
Pompei et al. (2009)	MRT	178	20 - 45	n.a.	24 female, 12 male	36 / 178 with a third head, from that 24 female and 12 male
Kiliç et al. (2010)	anatomic	49	23 - 76	n.a.	10 female, 16 male	17 / 49 with a third head, one was sortet out, 9 male, 7 female
Abe et al. (2011)	anatomic	30	62 - 85	n.a.	5 female, 10 male	n.a.

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