MAGNETIC RESONANCE IMAGING OF THE LATERAL PTERYGOID MUSCLE IN TEMPOROMANDIBULAR DISORDERS

XIAOJIANG YANG

Department of Prosthetic Dentistry and Stomatognathic Physiology and Department of Oral and Maxillofacial Surgery, Institute of Dentistry, Department of Diagnostic Radiology, University of Oulu

OULU 2002
XIAOJIANG YANG

MAGNETIC RESONANCE IMAGING OF THE LATERAL PTERYGOID MUSCLE IN TEMPOROMANDIBULAR DISORDERS

Academic Dissertation to be presented with the assent of the Faculty of Medicine, University of Oulu, for public discussion in the Auditorium I of the Institute of Dentistry, on April 19th, 2002, at 12 noon.

OUHUN YLIOPISTO, OULU 2002
Yang, Xiaojiang, Magnetic resonance imaging of the lateral pterygoid muscle in temporomandibular disorders

Department of Prosthetic Dentistry and Stomatognathic Physiology, Institute of Dentistry, and Department of Oral and Maxillofacial Surgery, Institute of Dentistry, University of Oulu, P.O.Box 5281, FIN-90014 University of Oulu, Finland, Department of Diagnostic Radiology, University of Oulu, P.O.Box 5000, FIN-90014 University of Oulu, Finland

Oulu, Finland

2002

Abstract

The fact that the lateral pterygoid muscle (LPM) and related symptoms play an important role in temporomandibular disorders (TMD) is widely recognized. In the study reported here, the LPM was investigated by magnetic resonance imaging (MRI) of patients with TMD. The visibility of the LPM in MRI with different projections was analyzed and a new imaging projection, condyle-the lateral pterygoid muscle projection (CLPM), for the LPM in MRI was introduced. Normal and abnormal findings of the LPM was compared with clinical symptoms of TMD.

Compared with sagittal imaging of temporomandibular joint (TMJ), CLPM images and most of the oblique sagittal imaging were able to show the LPM clearly. Hypertrophy, atrophy and contracture of the LPM were found in TMJs either with disc in normal position or with disc displacements. Pathological changes of the superior belly and hypertrophy of the inferior belly combined with various pathological changes of the superior belly were the most frequently observed abnormal imaging findings of the LPM in TMD. The pathological changes of the LPM were associated with the main clinical symptoms of TMD. In patients with symptomatic condyle hypermobility, the pathological changes of the LPM and related symptoms were associated with the clinical symptoms of TMJs with disc in normal position. The imaging abnormalities of the LPM were common in TMJs with disc displacements and seemed to be fewer in condyle hypomobility cases in TMJs with anterior disc displacement with non-reduction (ADDnr). However, normal imaging of the LPM was also found in TMJs with severe osteoarthritic changes and disc displacement.

The recognition of muscle alterations may lead to a more specific diagnosis and improve the understanding of the clinical symptoms and disease pathophysiology of TMD.

Keywords: TMJ, TMD, lateral pterygoid muscle, MRI
Acknowledgement

I would like to express my deep and sincere gratitude to my supervisor, Professor Aune Raustia, D.D.S., Ph.D., Head of the Department of Prosthetic Dentistry and Stomatognathic Physiology, Institute of Dentistry, University of Oulu. Her wide knowledge and her logical way of thinking have been of great value for me. Her understanding, encouraging and personal guidance have provided a good basis for the present thesis.

I am deeply grateful to my supervisor, Professor Kyösti Oikarinen, D.D.S., Ph.D., Head of the Department of Oral and Maxillofacial Surgery, Institute of Dentistry, University of Oulu, for his detailed and constructive comments, and for his important support throughout this work.

I wish to express my warm and sincere thanks to Professor Min Hong, D.D.S., Ph.D., Head of the Department of Oral and Maxillofacial Surgery, General Military Hospital, Beijing, China, who introduced me to the field of oral maxillofacial surgery and Professor Kurt Schellhas, M.D., Director of Neuroimaging and Spinal Injection Procedures, Center for Diagnostic Imaging, Minnesota, USA, whose letters gave me important guidance during my first steps into MR imaging studies. Their ideals and concepts have had a remarkable influence on my entire career in the field of temporomandibular joint research.

I owe my most sincere gratitude to Professor Eric Fossion MD, LDS, and Professor Antoon De Laat, LDS, GHO, who gave me the opportunity to work with them in the Department of Oral and Maxillofacial Surgery at the Catholic University of Leuven in Belgium and gave me untiring help during my difficult moments.

I warmly thank Dr. Hannu Pernu, D.D.S., M.D., for his valuable advice and friendly help. His extensive discussions around my work and interesting explorations in operations have been very helpful for this study.

My warm thanks are due to Professor Juhani Pyhtinen, M.D., Ph.D., and Professor Changzu Fan, M.D., who directed me in magnetic resonance imaging studies. Their kind support and guidance have been of great value in this study.

My sincere thanks are due to the official referees, Docent Pentti Kemppainen, D.D.S., Ph.D., and Docent Osmo Tervonen, M.D., Ph.D., for their detailed review, constructive criticism and excellent advice during the preparation of this thesis.
I wish to thank Mr. Ahti Niinimaa, M.Sc., Ph.D., and Mr. Risto Bloigu, M.Sc., for their guidance in statistical analysis, and Dr. Petri Tiilikainen, D.D.S., for his essential assistance in reviewing the patient files of this study.

I am grateful to Docent Kimmo Lehtimäki, D.D.S., Ph.D., for attracting me to Finland and for interesting discussions on the operations of the temporomandibular joint.

I also wish to thank Mrs. Anna Vuolteenaho, M.A., for revising the English of my manuscript. Ms Liisa Kärki, Ms Seija Leskelä and Ms Taru Kaleva are thanked for their excellent photographic work, and Ms Sinikka Vuoti and Ms Eija Takkula for their sympathetic help in secretarial work.

During this work I have collaborated with many colleagues for whom I have great regard, and I wish to extend my warmest thanks to all those who have helped me with my work in the Department of Prosthetic Dentistry and Stomatognathic Physiology in Oulu, in the Department of Oral and Maxillofacial Surgery and in the Department of Diagnostic Radiology at the University of Oulu, at Tampere University Hospital, at Leuven University Hospital in Belgium, and at General Military Hospital in Beijing, China.

I owe my loving thanks to my wife Xiaoping Liang, my sons Zou yi Yang and Zichao Liang. They have lost a lot due to my research abroad. Without their encouragement and understanding it would have been impossible for me to finish this work. My special gratitude is due to my brother, my sisters and their families for their loving support. My loving thanks are due to Raili and Pentti Rantanen. They let me own a happy family in Finland.

The financial support of the University of Oulu is gratefully acknowledged.

Oulu, Finland, February 2002

Xiaojiang Yang
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADDnr</td>
<td>anterior disc displacement with non-reduction</td>
</tr>
<tr>
<td>ADDr</td>
<td>anterior disc displacement with reduction</td>
</tr>
<tr>
<td>CT</td>
<td>computed tomography</td>
</tr>
<tr>
<td>EMG</td>
<td>electromyography</td>
</tr>
<tr>
<td>LPM</td>
<td>the lateral pterygoid muscle</td>
</tr>
<tr>
<td>MR</td>
<td>magnetic resonance</td>
</tr>
<tr>
<td>MRI</td>
<td>magnetic resonance imaging</td>
</tr>
<tr>
<td>PD</td>
<td>proton-density</td>
</tr>
<tr>
<td>RF</td>
<td>radiofrequency</td>
</tr>
<tr>
<td>TE</td>
<td>echo delay time</td>
</tr>
<tr>
<td>TMD</td>
<td>temporomandibular disorders</td>
</tr>
<tr>
<td>TMJ</td>
<td>temporomandibular joint</td>
</tr>
<tr>
<td>TR</td>
<td>pulse repetition time</td>
</tr>
</tbody>
</table>
List of original publications

This thesis is based on following articles, which are referenced to in the text by Roman numerals:


## Contents

Abstract
Acknowledgements
Abbreviations
List of original publications

1 Introduction ........................................................................................................... 15
2 Review of literature ............................................................................................... 16
  2.1 Diagnostic criteria of TMD............................................................................. 16
  2.2 Imaging of TMJ ............................................................................................. 17
    2.2.1 Plain film radiography ............................................................................. 17
    2.2.2 Panoramic radiography ........................................................................... 18
    2.2.3 Tomography ............................................................................................ 18
    2.2.4 Arthrography .......................................................................................... 19
    2.2.5 Computed tomography ............................................................................ 20
    2.2.6 Magnetic resonance imaging .................................................................. 20
      2.2.6.1 Physical principles ............................................................................ 20
      2.2.6.2 MRI of TMJ .................................................................................... 21
  2.3 Lateral pterygoid muscle (LPM) ..................................................................... 22
    2.3.1 Anatomy of the LPM ............................................................................. 22
    2.3.2 Electromyography of the LPM ............................................................... 23
    2.3.3 Clinical examination of the LPM ............................................................ 24
    2.3.4 Imaging of the LPM ................................................................................. 24
      2.3.4.1 Imaging projections .......................................................................... 24
      2.3.4.2 Imaging evaluation of skeletal muscle .............................................. 25
  3 Aims of the study ................................................................................................. 27
4 Materials and methods ........................................................................................... 28
  4.1 Materials ......................................................................................................... 28
    4.1.1 General information on patients.............................................................. 28
    4.1.2 Information from patient files ................................................................. 29
  4.2 Magnetic resonance imaging technique .......................................................... 29
    4.2.1 MRI equipments and parameters ......................................................... 29
    4.2.2 Imaging projections ................................................................................. 30
1 Introduction

Temporomandibular disorders (TMD) are pain and dysfunction syndromes involving the temporomandibular joint (TMJ) and/or muscles of mastication. The symptoms of TMD include clicking of TMJ, pain, and abnormal movement of mandible. Displacements of the disc appear in TMJ, and various degenerative changes can occur in the condyle and disc. The diagnosis of TMD is one of the focuses in dental clinical practice.

In the past decades, imaging diagnosis of TMJ has developed very fast. These advances have included arthrography, computed tomography (CT) and magnetic resonance imaging (MRI). Among these methods, it has been presented that MRI can give more accurate information of TMJ, e.g. on disc displacement, osteoarthritic changes of condyle, deformities of the disc, and pathological situations of surrounding soft tissues of TMJ. MRI findings have also been compared with surgical findings, anatomical and histological observations of autopsy specimens. It has been suggested that MRI is the best method in imaging diagnosis of TMD.

The studies presented on MRI have mainly discussed the disc displacements of TMJ. However, it has been found that pain and dysfunction symptoms of TMJ vary in patients with or without disc displacements. Alterations of the clinical symptoms of TMJ cannot always be explained only by disc displacements. The function and dysfunction of masticatory muscles should also be taken into account.

Previous studies have shown that the lateral pterygoid muscle (LPM) may play an important role in TMD. Stable and reliable methods to evaluate the LPM are still lacking. MRI has been confirmed as an important tool in diagnosing muscular diseases. In the study reported here MRI was used in imaging diagnosis of the LPM with the aim of detecting pathological changes of the LPM in patients with TMD and of discussing the correlations of the imaging abnormalities with the clinical symptoms.
2 Review of literature

2.1 Diagnostic criteria of TMD

A multitude of terms have been used to describe patients presenting with pain and dysfunction of the temporomandibular joint (TMJ) and related masticatory muscles: Costen’s syndrome (Costen 1934), dysfunctional temporomandibular joint and muscle pain (Ramfjord 1961), myofascial pain dysfunction (MPD) (Laskin 1969), temporomandibular joint syndrome (Carraro et al. 1969), mandibular dysfunction (Thompson 1971) and craniomandibular disorders (McNeill 1990). These terms include several entities that have different etiology, but present with similar signs and symptoms (Westesson 1993).

Temporomandibular disorders (TMD) are one subgroup of any of these terms, and they embrace a number of clinical problems that involve the masticatory muscles and/or the temporomandibular joint (Laskin 1969, Agerberg & Carlsson 1975, McNeill et al. 1990, Westesson 1993). This term is most frequently used in clinical practice (Raustia et al. 1994, Eberhard et al. 2000, Steed & Wexler 2001).

The studies of internal derangement of TMJ (TMJID) focus on displacement of the disc in temporomandibular joint (Farrar 1978, Wilkes 1978ab). Wilkes defined the criteria of TMJID in 1978. The criteria were based on clinical symptoms, surgical findings, radiological findings, and they were later combined with MRI findings of TMJ (Wilkes 1989, Schellhas 1989a). In past decades, a number of reports have been presented indicating that the disc displacement is associated with the pain and dysfunctional symptoms of TMJ (Farrar & McCarty 1979, Schellhas 1989a, Katzberg et al. 1996, Emshoff et al. 2001). The studies also showed that the disc displacement correlated with disc deformity (Yoshida et al. 2000, Taskaya-Yilmaz & Ogutcn-Toller 2001) and osteoarthritic changes of the hard tissues in TMJ (Westesson 1985, Kurita et al. 2000, Bertram et al. 2001). The pathological evidence in TMJs with disc displacement have been confirmed by histological (Larheim et al. 1999, Leonardi

However, some questions have arisen based on the clinical studies. In Wilkes’s criteria, the internal derangement of TMJ was described as a progressing procedure in radiological stages; oppositely, clinical symptoms show as a chronically released procedure (Wilkes 1989). The symptoms of some patients might be relieved after conservative or surgical treatment, but the severe disc displacement and degenerative changes of TMJ might still exist (Montgomery et al. 1992, Sato et al. 1999, Nishimura 2001). Other reports found that the symptoms of the patients with severe disc displacement of TMJ might be resolved even without any treatment (Lundh et al. 1992, Kurita at al. 1998, Sato et al. 1998). On the other hand, pain and dysfunction symptoms have also been found in TMJs without disc displacement (Benito et al. 1998). The results of these studies indicate that the disc displacements of TMJ cannot always explain the alterations of the clinical symptoms. If the views only encompass disc displacement, it may not be enough for the diagnosis and treatment of TMJ problems. The function and dysfunction of the masticatory muscles in TMD should also be taken into account (Helkimo 1974a,b, Solberg 1986a, Katzberg et al. 1996, De Laat 1998, Greene 2001). Identification of pathological changes of masticatory muscles is still lacking in diagnostic criteria of TMD, and more evidence of pathological changes of the masticatory muscles in TMD is needed.

2.2 Imaging of TMJ

Most studies agree that TMD cannot be diagnosed only on the basis of findings by clinical examinations. Imaging diagnosis is very important (Wilkes 1989a,b, Westesson et al. 1989, Gibbs et al. 1998). There are a number of imaging techniques, ranging from plain-film to MRI, that have been used in diagnosis of TMD. Arthroscopy is applied as a treatment for TMD rather than a diagnosis technique (Barkin & Weinberg 2000, Holmlund et al. 2001). Nuclear medicine imaging is rarely used for clinical diagnosis of TMD (Matin 1983). These two methods are therefore not included in this review.

2.2.1 Plain film radiography

Plain films of TMJ are made with a stationary x-ray source and film. In order to avoid superimposition of adjacent anatomic bony structures making visualization of all parts of TMJ, different projections of transcranial films have been applied, which include oblique transcranial view, transmaxillary view, submental-vertex view and transpharyngeal view (DelBalso 1990, Kopp & Rockler 1979, Kononen & Kilpinen 1990, Williamson et al. 1999). Transcranial plain films have been used in the past to
diagnose TMD by evaluating the position of the mandibular condyle in the glenoid fossa and condylar osseous changes (Weinberg 1979, van Sickels et al. 1983, Kononen & Kilpinen 1990). However, some studies have reported that the relationship between the condyle and the glenoid fossa could not be accurately evaluated in transcranial film by comparing with tomography of TMJ (Pullinger et al. 1985, Knoernschild et al. 1991). Concordance in the degree of condylar displacement was found in only 60% of the cases when comparing transcranial film and tomography (Pullinger & Hollender 1985). Currently, transcranial plain film is suggested to be a method for detecting condylar fractures rather than a method for diagnosing TMD (Lindqvist et al. 1988, Brooks et al. 1997, Thoren et al. 2001).

2.2.2 Panoramic radiography

Panoramic radiography used to be considered a good imaging method for evaluating TMJ since information about the teeth and other parts of the jaws were also shown on the image (Kononen & Kilpinen 1990, Howard 1990). However, the relationship between the condyle and glenoid fossa cannot be evaluated in the panoramic film because the fossa cannot be seen with superimposition of the base of the skull and zygomatic arch. The morphology of the condyle becomes wider than the anatomic structure of the condyle (DelBalso 1990). The agreement between panoramic radiographs and lateral tomograms on osseous changes of the condyle is 60% to 70% (Habets et al. 1989, Ludlow et al. 1995). Panoramic radiography has also been used in evaluating condyle fractures (Silvennoinen et al. 1998).

2.2.3 Tomography

Tomography of TMJ is generated through the synchronous movement of the x-ray tube and film cassette through an imaginary fulcrum located in the center of the desired imaging plane. Linear tomography and complex tomography are involved (DelBalso 1990).

Osseous changes in TMJ. Several studies have attested that tomography is a good method for depicting the osseous changes with arthrosis in TMJ (Berrett 1983, Rosenberg & Graczyk 1986). In studies of TMJ specimens obtained at autopsy, tomography has been shown to represent the anatomic structures better than transcranial radiography (Lindvall et al. 1976, Eckerdal & Lundberg 1979). Observer performance studies in the assessment of tomographic images have shown a 60% to 80% interobserver agreement and a similar intra-observer agreement (Kopp & Rockler 1978, Petersson & Rohlin 1988, Rohlin & Peterson 1989, Cholitgul et al. 1990).

Condyle position. For evaluation of condyle position in glenoid fossa of TMJ, tomography has been reported to be more reliable than plain film and panoramic.
radiography in a study comparing the three methods (Ludlow et al. 1995). Tomography has been used for evaluating the condyle position and joint space in many reports (Knoernschild et al. 1991, Kuboki et al. 1999, Ozawa et al. 1999). However, numerous studies have shown that condyle position appears to be highly variable in both asymptomatic (Pullinger et al. 1985, Blaschke & Blaschke 1981) and symptomatic subjects (Brand et al. 1989, Pullinger et al. 1986). On the other hand, the relationship between the condyle position and disc displacement is uncertain. The condyle position is not reliable in estimating the disc displacement of TMJ and related symptoms (Katzberg et al. 1983, Bonilla-Aragon et al. 1999, Kurita et al. 2001). Clinically, condyle position is still an important aspect in orthognathic surgery (Williamson et al. 1999, Arat et al. 2001) and orthodontic studies (Major et al. 1997, Zhou et al. 1999). The major disadvantage of tomography is the lack of visualization of the soft tissue of TMJ, a problem shared with plain film radiography.

### 2.2.4 Arthrography

The technique of TMJ arthrography was introduced in the 1940s (Nørgaard 1947), but it was not extensively used until the late 1970s (Westesson et al. 1980, Westesson 1993). Arthrography improved rapidly after the late 1970s (Wilkes 1978, Farrar & McCarty 1979, Katzberg et al. 1979). There are two technical methods for arthrography of TMJ. In single-contrast arthrography, radiopaque material is injected into either the lower or upper joint space, or into both compartments (Wilkes 1978a,b, Brand 1990). In double-contrast arthrography, a small amount of air is injected into the joint space after the injection of contrast materials (Westesson et al. 1980, Westesson 1982, Ma 1987). A comparative study reported that there was no statistically significant difference in the diagnostic accuracy between these two techniques (Westesson & Bronstein 1987).

Several studies have shown that arthrography is an accurate imaging method for evaluating anterior disc displacement. The accuracy for diagnosing the position of the disc ranged from 84% to 100% compared with the corresponding cryosectional morphology and surgical findings (Westesson & Rohlin 1984a, Westesson et al. 1986, Tanimoto et al. 1989, Schellhas et al. 1988). Perforation and adhesion of the disc can also be shown by this technique (Helms et al. 1980, Westesson et al. 1986, Schellhas et al. 1988, Ryan et al. 1990). These studies have given important evidence for diagnosis and identification of TMJ internal derangement (Wilkes 1989). Arthrography is based on plain film (Helms et al. 1980, Van Sickels et al. 1983) and tomography (Wilkes 1978a,b, Katzberg et al. 1979). A recent study reported that using the arthrography technique might improve the accuracy of diagnosing perforations and adhesions of the disc in magnetic resonance imaging of TMJ (Toyama et al. 2000).

There are some advantages of this technique. Arthrography is a method that depends upon more technical training and experience in the observation of images, it also has minimally invasive (Westesson et al. 1993).
2.2.5 Computed tomography


In an earlier report, the accuracy for disc displacement was high (81%) when comparing imaging observations of CT and surgical findings (Thompson et al. 1984). Some reports considered that CT might replace the technically difficult and invasive arthrography in the diagnosis of disc displacement in TMD (Helms et al. 1982, Avrahami et al. 1984, Cohen et al. 1985). However, the accuracy of the disc displacement was only 40%-67% in CT in studies of autopsy specimen materials (Westesson et al. 1987b, Tanimoto et al. 1990). The accuracy of osseous changes of TMJ in CT compared with cadaver material was 66%-87% (Tanimoto et al. 1990, Westesson et al. 1987a). Some reports pointed out that radiographic evidence of arthrosis may or may not be associated with clinical symptoms of pain dysfunction. Thus patients without osseous changes in TMJ may have pain, and those with clear signs of bony abnormalities may be pain-free (Westesson 1993, Brooks et al. 1992, Bertram et al. 2001). CT was not considered as a good method for the diagnosis of TMD in many later reports (Katzberg 1989, Kaplan & Helms 1989, Helms & Kaplan 1990, Westesson 1993, Brooks et al. 1997).

2.2.6 Magnetic resonance imaging

2.2.6.1 Physical principles

Magnetic resonance imaging (MRI) is unique in that there is no associated risk of ionizing x-ray. For MRI, the patient placed in a strong static magnetic field. The hydrogen nuclei, or protons, in the body align with the direction of the main magnetic field, a short radiofrequency (RF) pulse at the proper frequency and duration is then transmitted into the body. The protons absorb RF energy and flip over into a plane that is at an angle with the direction of the main magnetic field, the protons reemit some of the absorbed energy, which induces an electric current in a specially designed RF receiver coil. The induced current, so-called the magnetic resonance (MR) signal, is then transformed into an image by computerized mathematical methods (Jarenwattananon & Gentry 1990).

An MR image is produced from signals coming from the hydrogen nuclei, or protons, in the body. The contrast of the image is provided by differences in signal intensity from protons in different tissues. Several parameters affect the signals intensity: (1) amount of the hydrogen nuclei in tissue; (2) the characteristics of the tissue, as determined by two different relaxation time constants (\(T_1\) and \(T_2\)); (3) the bulk flow of protons in tissues. Varying the pulse sequence imaging variables, such as pulse repetition time (\(TR\)) or echo delay time (\(TE\), allows discrimination of different
tissues. Special selected parameters can generate images in which contrast differences are dependent on these factors. The most frequently used ones in TMJ images are $T_1$-weighted image (short TR and TE), $T_2$-weighted image (long TR and TE) and proton-density ($PD$) image (long TR and short TE) (Jarenwattananon & Gentry 1990). Typical values for $T_2$ in tissue range from 0.02 to 0.30 seconds. In general, the more water a tissue contains, the longer the $T_2$. Thus, areas of long $T_2$ can be interpreted as areas of edema, effusion, or inflammation. Typical $T_1$ values for tissue range from 0.2 to 3 seconds. Much of the power of MRI comes from the fact that various tissues have different values of $T_1$ and $T_2$ and contrast can be varied over a wide range by adjusting TE and TR (Kircos & Ortendahl 1990). For example, in $T_1$-weighted and PD image, the fibrocartilaginous disc is in low signal intensity. The lateral pterygoid muscle (LPM) and bilaminar zone are of intermediate signal intensity. The position and morphology of the disc can be clearly observed (Katzberg et al. 1985). However, in a $T_2$-weighted image, the disc, muscles and bilaminar zone are all in low signal intensity, effusion (if it exists) of the bilaminar zone or in joint compartments can be well observed with high-intensity signal (Schellhas & Wilkes 1989). Skeletal muscles, fibrous, blood and fat tissues all have their own characteristic signal intensities in MRI (Siegelman & Outwater 1999, Weinreb et al. 1985, Murphy et al. 1986).

2.2.6.2 MRI of TMJ

MRI with surface coil was introduced applied to TMJ imaging in the 1980s (Harms et al. 1985, Katzberg et al. 1986, Schellhas et al. 1986). Several studies have compared MRI of TMJ with arthrography and CT (Schellhas et al. 1988, Liedberg et al. 1996, Trumpy et al. 1997). The MRI findings were also compared with anatomical and histological observations (Westesson et al. 1987ab, Larheim et al. 1999). In studies on autopsy specimens, the accuracy of MRI in evaluating osseous changes in TMJ was 60% to 100% (Westesson et al. 1987b, Hansson 1989, Tasaki & Westesson 1993) and the accuracy in evaluating disc displacement was 73% to 95% (Westesson et al. 1987b, Hansson 1989, Schwaighofer et al. 1990, Tasaki & Westesson 1993). All these studies showed that MRI was the best method of imaging both the hard and soft tissues of the TMJ (Raustia et al. 1995, Brooks et al. 1997, Gibbs et al. 1998).

Several studies have confirmed that disc displacement in MRI showed close associations with clicking, pain and other dysfunction symptoms of TMJ (Katzberg et al. 1996, Rammelsberg et al. 1997, Emshoff et al. 2001, Bertram et al. 2001). MRI was considered as a golden standard to evaluate the disc position (Gibbs et al. 1998). Whenever the clinical pain and dysfunction symptoms of TMJ were found to have no relationship with disc displacement in MRI, a false-positive or false-negative imaging diagnosis was suspected (Haley et al. 2001).

Although many studies agree that muscular pain is another major aspect of TMD (Solberg 1986, Greene & Laskin 1988, Rauhala et al. 1999, Molina et al. 2000, Greene 2001, De Laat 2001), the evidence of pathological changes of the masticatory muscles may have been ignored in imaging diagnosis. The results of some reports have shown that MRI is not only an accurate method to detect the disc position but also a potential technique to evaluate the pathological changes of the masticatory muscles in TMD.
(Katzberg et al. 1985, Schellhas 1989, van Spronsen et al. 1989, Westesson 1993, Quemar et al. 1993). However, no reports concerning the relationship between the abnormalities of the masticatory muscles in MRI and clinical symptoms have been published.

2.3 Lateral pterygoid muscle (LPM)

2.3.1 Anatomy of the LPM

In the past decades, the lateral pterygoid muscle (LPM) has been given more attention than other masticatory muscles in studies of TMJ problems.

According to Sicher (1965), the LPM arises with two bellies, the smaller superior belly of the LPM (SLP) runs posteriorly from the infratemporal surface of the greater sphenoid wing in an inferior and lateral direction to the crest of the eminence, where its fibers become more horizontal and insert into the condyle and disc. The larger inferior belly of the LPM (ILP) ran posteriorly and laterally from the outer surface of the lateral pterygoid plate to insert into the pterygoid fovea. The two bellies are separated anteriorly by a variably wide gap and fuse in front of the TMJ. The nerve to the LPM branches off the masseteric or the buccal nerve. The blood supply is a branch of the maxillary artery (Sicher 1965). Other reports argued that there are three patterns of nerve supply to the LPM. In the two most frequently observed patterns, both bellies of the LPM were supplied from a common source that was derived from either the long buccal or mandibular nerve. In the third pattern, independent branches to either belly arose from deep temporal, long buccal or mandibular nerve (Aziz et al. 1998). The results of Aziz's study indicated that both bellies of the LPM were usual supplied by a common proximate source, but each belly also received an independent nerve in every case. The functional activities of the two bellies of the LPM might act as separate muscles (Juniper 1981, Aziz et al. 1998).

The theory of internal derangement of TMJ involves anterior disc displacements, which were in earlier studies considered to be brought about by the abnormal activities of the superior belly of the LPM (Juniper 1984, Porter 1970, Osborn 1985). Some anatomical studies supported this point of view by the observation that the superior belly of the LPM inserts into the capsule and disc (Thilander 1964, Honee 1972). However, later studies showed that the superior belly of the muscle inserted into the condyle, capsule and disc (Bertilsson & Strom 1995, Naidoo 1996). Other reports found that the insertion of the LPM might only be firmly attached but not inserted into the disc (Wilkinson 1988, Heylings et al. 1995). The results of these studies presented that from an anatomical point of view it was impossible for the superior belly of the LPM to pull the disc forward independently from the condyle, leading to the disc anterior displacement. Furthermore, other reports presented that not only the superior belly but also the inferior belly of the LPM might have some fibers inserted into the disc (Schmolke 1994, Bittar et al. 1994, Fujita et al. 2001). The relationship between disc displacement and dysfunction of the LPM is still unclear. In a bilateral
comparative anatomical study of TMJ, Grunert et al. (2000) reported that an evident hypertrophy of the superior belly of the LPM was found in the TMJs with disc pathological changes or osseous changes of the condyle. The anatomical observation of the auriculotemporal nerve showed that the pathological changes of the LPM might compress or irritate the nerve and produce pain symptoms (Schmidt et al. 1998). Although the results of these studies may lead to the realization that the LPM may have a close association with TMJ disorders and involved symptoms, the clinical evidence showing pathological changes of the LPM in patients is still lacking.

2.3.2 Electromyography of the LPM


Studies concerning TMD have shown that abnormal electromyographic activities of the LMP could be detected in the patients (Juniper 1984, Friedman 1997). The abnormal EMG activities of the LPM were observed more obviously than those of other masticatory muscles in TMD cases (Lafreniere et al 1997). These studies showed that the LPM might play an important role in TMD. The basic evidence for understanding and discussing the function and dysfunction of the LPM comes mostly from the results of these studies.

However, many studies have found that EMG patterns of the LPM are not stable or reproducible (Mahan et al. 1983, Gibbs et al. 1984, Hiraba et al. 2000). The main reason is that it is difficult to place the electrodes correctly in the target belly, especially in the superior belly, because of the deep location and small size of the LPM (McNamara 1973, Mahan et al. 1983, Hiraba et al. 2000). If the insertion of the electrode to the superior belly of the LPM is too high, too deep or in an unsuitable angle, the electrode may be placed in the deep fibers of the anterior temporal muscles or in the inferior belly of the LPM (Juniper 1981, Widmalm et al. 1984, Orfanos et al. 1996). Therefore, it was assumed that the electrodes from the superior LPM belly were implanted in the other muscle or other belly. Data for superior belly of the LPM might be discarded (Mahan et al. 1983). Some special devices were used in other studies, which attempted to standardize the trajectory for electrode placement (Koole et al. 1990, Yoshida et al. 1999, Hiraba et al. 2000), but the EMG patterns of each belly of the LPM were still not well reproducible (Hiraba et al. 2000). Other report pointed out that there was no evidence to confirm that the electrodes were placed in the target belly, so CT was suggested to be used as an imaging guide for insertion of the electrode (Orfanos et al. 1995). Clinically it seems impossible to make two or more CT scans on the patients to locate the electrode. Even if the wires are initially accurately placed in the target muscle, the wires may be displaced and enter the adjacent muscles during
EMG recording (Jonsson & Bagge 1968, Wood et al. 1986). How to make a stable and reliable EMG for the LPM is still an open question.

2.3.3 Clinical examination of the LPM

Evaluating muscle status is of primary importance in the clinical examination of patients with masticatory pain and TMD. Muscle palpation has been widely applied as a reliable method (Solberg 1986, Katzberg et al. 1996, Molina et al. 2000, Isselee et al. 2001). Intraoral palpation of the inferior belly of the LPM was considered a standard examination method to evaluate the LPM (Schwartz & Chayes 1966). Pain and tenderness of the LPM were recorded in many reports when using this method (Campell et al. 1982, Wanman & Agerberg 1986, Sindet-Pedersen 1988, Ai & Yamashita 1992). Pain and tenderness of the LPM were recorded in many reports when using this method (Campell et al. 1982, Wanman & Agerberg 1986, Sindet-Pedersen 1988, Ai & Yamashita 1992). Palpatation pain of the LPM was reported significantly more than of other masticatory muscles in patients with TMD (Gross & Gale 1983). This method is still used and referred to in current studies (Molina et al. 2000, Liu et al. 2000).

However, other reports suspected that intraoral palpation of the inferior belly of the LPM might give an unreliable evaluation by false palpation of the superficial belly of the medial pterygoid muscle (Johnstone & Templeton 1980). The positive result of pain in the LPM by intraoral palpation was found to be higher than by functional manipulation of the LPM in both asymptomatic and masticatory pain groups (Thomas et al. 1987). An anatomical study on specimens reported that it was nearly impossible to palpate the inferior belly anatomically. False-palpations of the medial pterygoid muscle and the deep tendon of the temporal muscle might have happened (Stratmann et al. 2000). Functional manipulation or provocation of the LMP was suggested to replace the intraoral palpation method (Thomas et al. 1987, Stratmann et al. 2000).

2.3.4 Imaging of the LPM

2.3.4.1 Imaging projections

The LPM can be observed in MR images of TMJ with different imaging projections. The identifications of imaging projections for TMJ came from the concepts of radiography and tomography practices (Aquilino et al. 1985, Gillespy & Helms 1986, Farman & Farman 1999). In these techniques, the projections are dependent on head position, x-ray source and mandible position. If any of them are changed, the morphological structures of TMJ might be altered. Some special devices were developed to connect the relationship between patients’ heads and imaging equipment to obtain fine-quality images (Omnell & Petersson 1976). Some studies have found that the true coronal or sagittal plane was not the best scanning plane for showing the TMJ (Omnell & Petersson 1976, Rosenberg & Graczyk 1986). The plane, which is
perpendicular or parallel to the long axis of the condyle, might show the anatomic structures of TMJ better. Individual oblique sagittal and oblique coronal planes were suggested (Omnell & Petersson 1976, Rosenberg & Graczyk 1986). To find the true sagittal and coronal plane was already difficult in radiographic or tomographic techniques, so it was not easy to make oblique images of TMJ with these techniques (Quemar et al. 1993).

MR images are made from signals that are obtained from the three-dimensional gradient magnetic field. Slice position of MRI can be adjusted by changing the frequency of RF excitation. Only protons on the selected plane that are excited by RF will contribute to the image, so-called selective irradiation. RF can be selected in any directions in the three axes of gradient fields (Kircos & Ortenahl 1990). In the MRI technique, oblique images of TMJ are easy to be settled (Laurell 1987, Shellock & Pressman 1989, Musgrave et al. 1991). Furthermore, MRI allows imaging planes to be settled in any interesting section (van Sprosen et al. 1991, Chen et al. 2000). In some studies the anatomical cross-section and coronal planes were applied to show the masticatory muscles in CT or in MRI (Raustia et al. 1986, Kahl-Nieke & Fischbach 1999, van Sprosen et al. 1989). The anatomical cross-section and coronal plane was nearly perpendicular or parallel to the long axis of the masseter muscle, temporal muscle and medial pterygoid muscle. Later studies have used the selected scanning plane in MRI that is perpendicular to the main fibers direction of these masticatory muscles to obtain maximal cross-section of the muscles (van Sprosen et al. 1989, van Sprosen et al. 1991).

The LPM can be observed on coronal and sagittal MR imaging of TMJ (van Sprosen et al. 1989, Schellhas 1989b). Sagittal and oblique sagittal images of TMJ are the most important images in TMD diagnosis, which can show disc, condyle, fossa and sometimes the LPM on the same film (Katzberg et al. 1985, Schellhas 1989$a,b$, Benito et al. 1998). However, there are no systematic reports on whether the anatomic structures of LPM can be shown clearly in different imaging projections.

2.3.4.2 Imaging evaluation of skeletal muscle

Imaging evaluation of the skeletal muscles can be obtained by CT, ultrasonography and MRI. However, CT and ultrasonography provide a limited capability for tissue characterizations. Many tissues i.e. fat, fluid, and fibrous can be well identified by MRI (Siegelman & Outwater 1999).

The characteristics of MR imaging signal intensity of normal and diseased muscle tissues have been reported (Weinreb et al. 1985, Murphy et al. 1986). MRI diagnosis of hypertrophy (Bertorini et al. 1994, Jacobs et al. 1994, Petersilge et al. 1995, Thyagarajan et al. 1998), atrophy (Kader et al. 2000, Katz & Ropper 2000) and contracture (Chen et al. 1998) of skeletal muscles were reported in studies dealing with pain symptoms in the calf, lower back and shoulder. These pathological changes of the muscles were found to be associated with pain and dysfunctional symptoms. MRI has been accepted as an important tool to evaluate muscle diseases (Shellock & Fleckenstein 2000).
Imaging evaluations of masticatory muscles have also been reported. Ultrasonography has been applied in measuring the thickness of the masseter muscle (Raadsheer et al. 1994). CT has been used in evaluating the density changes of the masticatory muscles (Weijs & Hillen 1984, Raustia et al. 1986, van Spronsen 1989). A previous study found that the density changes of the LPM in CT might be more significant than those of other masticatory muscles in patients with TMD (Raustia et al. 1998). MRI has been reported in the diagnosis of hypertrophy of the masseter muscle (Fyfe et al. 1999, Murakami et al. 2000, Kim et al. 2000) and temporal muscle (Gniadecka et al. 1997). Schellhas (1989b) has discussed preliminarily the characteristics of pathological changes of the masticatory muscles in MRI. Only a few studies have referred to the normal and abnormal findings of the LPM in MRI (Katzberg et al. 1985, Schellhas 1989b, Quemar et al. 1993). However, systematic studies concerning pathological changes of the LPM in MRI are lacking, and there are no reports of the relationships between the pathological findings of the LPM and clinical symptoms of TMD.

Previous studies have shown that the LPM plays an important role in TMD. It is still difficult and unreliable to diagnose the dysfunction and pathological changes of the LPM by EMG and clinical examination. It seems that MRI is a promising method for obtaining more evidence of the pathological changes of this muscle.
3 Aims of the study

The aims of this study were to investigate pathological changes of the LPM by MRI in patients with TMD. Specific aims were:

1. To evaluate the visibility of the lateral pterygoid muscle in MRI of TMJ with different projections.
2. To define MRI findings of the lateral pterygoid muscle in patients with TMD.
3. To compare MRI findings of the lateral pterygoid muscle with the clinical symptoms of TMD.
4. To compare MRI findings of the lateral pterygoid muscle and disc position of TMJ.
5. To analyze pathological changes of the lateral pterygoid muscle in different types of TMD.
4 Materials and methods

4.1 Materials

4.1.1 General information on patients

The analysis of the visibility of the LPM in different projections of MR imaging was based on 28 patients with TMD symptoms (10 males, 18 females, 20-60 years of age, mean 33.5 years) and five volunteers defined by the clinical absence, in the past or present, of any sign or symptoms of TMD (2 males and 3 females, mean age 27.8 years) (Paper I).

The patients in other studies were based on 325 patients examined by MRI (650 TMJs; 239 females; 86 males; range 15 to 72 years; mean 41.2 years), because of TMD (1991 – 2002). The patients had been originally referred to the Oral and Maxillofacial Surgery Department of Oulu University Central Hospital for diagnostic examination and treatment of TMJ problems (Papers II-IV).

The relationship between pathological changes of the LPM and condyle mobility in MRI and clinical symptoms was based on the 98 cases with TMJ hypermobility (75 females, 23 males; range 15 to 72 years; mean 42.5 years) (Paper II).

The MRI abnormalities of the LPM in patients in late stage of TMD were based on 142 patients with bilateral or unilateral anterior disc displacement without reduction in TMJ in MRI (176 TMJs; 106 females; 36 males; range 19 to 72 years; mean 43.9 years)(Paper III).

Studies on disc positions, condyle mobility and clinical symptoms were based on 105 patients with bilateral or unilateral TMJ hypermobility in MRI (79 females; 26 males; range 15 to 72 years; mean 41.5 years)(Paper IV).
4.1.2 Information from patient files

For this retrospective study, information about clinical symptoms of the patients was obtained from the patient files. A specially designed form for recording the clinical symptoms of TMD was used with all the patients in this study. The same form was used in clinical follow up of the patients. The form included the following aspects, which related to this study:

- **Reason for seeking treatment** was recorded as the chief complaint of the patient.
- **Stomatognathic anamneses** included TMJ symptoms (clicking, tiredness, stiffness or pain), jaw movements symptoms (difficulty in opening, pain on opening, pain on other jaw movements, locking or subluxation), pain in other areas (headache, pain in neck, shoulder or back) and other dysfunctional symptoms in head and neck.
- **Main location of symptoms**: an illustration of head and neck showed the main location of the symptoms.
- **Palpation pain of the masticatory muscles**: palpation of temporal muscle, masseter muscle, medial pterygoid muscle and lateral pterygoid muscle (intraoral palpation) were performed. All pain symptoms were recoded on three scales: slight, mild or strong.
- **Symptoms on clinical examinations of TMJ** included palpation pain on lateral and posterior TMJ, restricted movement, locking, subluxation, clicking and crepitation.
- **Symptoms on mandibular movement**: Pain and clicking during these movements were also recorded.

Patients with collagen vascular disease or rheumatoid arthritis or severe trauma histories, i.e. mandibular or condyle fracture were excluded from this study.

4.2 Magnetic resonance imaging technique

4.2.1 MRI equipments and parameters

Before 1991 the studies were performed with a 0.3-T magnet (Fornor β-3000 Systemy); 1991-1996 with a 1.0-T magnet (Magnetom, Siemens), and after 1996, with a 1.5-T magnet (Signa, GE.) T1- weighted (200-400/12-20/1or2) (TR range/TE range/excitations), T2 - weighted (2000-3000/80-200/1) and Proton Density (PD) (2000-3000/14-30/1), with nine 3-mm-thick imaging slices, a 10X10 field of view (FOV) and a 256X192-256 or 128X128 (in 1.0-T) matrix were used for the images.
4.2.2 Imaging projections

All the patients underwent bilateral MRI examinations of the TMJ with TMJ surface-coil. Sagittal, oblique sagittal, coronal, oblique coronal and/or condyle-lateral pterygoid muscle (CLPM) projections were used in mouth-closed position. In maximally mouth-open position, only proton density (PD) oblique sagittal or CLPM and T1-weighted sagittal images were taken.

*Scout imaging*. The location of condyle and scanning planes was determined on cross-section scout imaging of TMJ. Before 2000, scout imaging was only made in mouth-closed position (Fig. 1). Scout imaging has been done in both mouth-closed and mouth-open positions since 2000.

*Sagittal and coronal imaging*. The scanning planes were located in anatomical sagittal (Fig.1A) and coronal direction (Katzberg et al. 1986).

*Oblique sagittal and oblique coronal imaging*. The scanning planes were perpendicular (Fig.1B) or parallel to the long axis of the condyle (Musgrave et al. 1991, Gibbs et al. 1998).

*Condyle-lateral pterygoid muscle (CLPM) imaging*. The scanning plane was passing through the condyle and parallel to the long axis of the main fiber direction LPM (Fig.1C).

4.3 Grading of MRI findings

4.3.1 Lateral pterygoid muscle

4.3.1.1 Visibility of the LPM in MRI

In order to compare findings of the LPM with disc and condyle situations, the LPM was observed in sagittal, oblique sagittal and CLPM imaging. Three levels were used for evaluating whether the LPM could be detected clearly in these images (Fig.2):

If two bellies of the LPM were shown clearly in the images, visibility of the LPM was referenced as $V_2$ (Fig.2A).

If only one belly was shown clearly in the images, visibility of the LPM was classified as $V_1$ (Fig.2B).

If neither belly of the LPM could be clearly observed in the images, visibility of the LPM was $V_0$ (Fig.2C).

Diagnosis was made only on images in which two bellies of the LPM showed clearly, and the same pathological finding was clearly observed on at least two slices of the image.
4.3.1.2 Normal MRI findings of the LPM

The normal structure of the LPM in mouth-closed MRI was seen as a fan-like muscle from the origins of the two bellies to the neck of the mandibular condyle or the disc (Schellhas 1989b, Quemar et al. 1993)(Fig.3). The superior belly of the LPM and the inferior belly of the LPM were separated by an evident gap with high signal layer in the anterior one-third near the origin sides, with a high signal layer in between (Fig.3A). The vessel may be found in the gap between the two bellies (Fig.3B). Two bellies were fused near the insertion of the condyle and could not be separated from each other in the imaging (Fig.3). The signal of normal muscle tissue was homogeneous intense on all MRI sequences (Weinreb et al. 1985, Murphy et al. 1986). In mouth-closed position, the upper and lower edges of the two bellies of the LPM were well identified.

4.3.1.3 Abnormal MRI findings of the LPM

Hypertrophy. Enlargement and increased size of muscles with homogeneous signal on all MRI sequences was considered to be a sign of hypertrophy of the skeletal muscles (Schellhas 1989b, Petersilge et al. 1995, Bertorini et al. 1994). Hypertrophy of the LPM was manifested as an obvious enlargement in the middle part of the belly, because the two ends of the belly were connected with the bony tissues. The hypertrophic belly of the LPM showed that the upper and lower edges of the belly changed into convex curves (Fig.4). Side-to-side comparing of each individual was noticed in diagnosis of hypertrophy (Fig.4).

Atrophy. Atrophy of the LPM was characterized by fatty replacement with high signals appearing in large areas in the muscles on short and long TR/short TE images with non-increased, or reduced size of the LPM (Schellhas 1989b)(Fig.5 &6). Atrophy of the LPM could be well identified in PD and T₂-weighted imaging (Fig.7).

Contracture. Contracture of the LPM presented as size of the muscles increased, at the same time fibrosis could be found as low signals in the muscles on PD and T2-weighted images (Schellhas 1989b)(Fig.7 & 8). Side-to-side comparing was also made in the diagnosis of contracture (Fig.7). Diagnosis was made only when the same pathological finding was shown clearly on at least two slices of the image.
4.3.2 Disc position

Disc position was diagnosed according to Katzberg et al. (1985). Normal disc position was defined as the juncture of posterior band of the disc, and bilaminar zone was located at the superior or 12 o’clock position relative to the condyle (Fig.9A&B). Anterior disc displacement was diagnosed when this juncture was anteriorly located. Anterior disc displacement with reduction (ADDr) was demonstrated if the anterior displaced disc could return to the top of the condyle in mouth maximal opening position (Fig.9C&D). If the anterior displaced disc remained in anterior position of the condyle in the maximal mouth open position, it was classified as anterior disc displacement with nonreducing (ADDnr) (Fig.9E&F).

4.3.3 Morphology of the disc

The morphology of the disc was assessed using the biconcave shape as the normal point of reference. Disc deformity was defined when folded, thickening changes of the disc, convex, or posterior band enlargement of the disc was found in the images (Yoshida et al. 2000, Milano et al. 2000, Sato et al. 1999).

4.3.4 Effusion

Effusion of TMJ defined as a high fluid signal was found in T2-weighted MR images. According to Schellhas (1989a), Effusion might be detected either in compartments of TMJ or in the bilaminar zone of the disc, or both.

4.3.5 Osteoarthritis

Diagnosis of osteoarthritis was made when one or more of the following signs were present on the condyle: flattening, osteophytes, erosions and sclerosis(Westesson 1985).

4.3.6 Condyle mobility
Condyle mobility was classified as hypomobility (limitation), normal mobility and hypermobility by MRI findings. For this procedure, a horizontal tangential line of the top of the articular fossa and a vertical line through the top of the articular eminence were made on sagittal or oblique sagittal image of TMJ. The two lines met in point “O”. From the point “O”, the articular eminence was divided by angles into three parts: 0°-90°, 90°-120° and 120°-180°. The top of the articular fossa was at 0° and the top of the articular eminence was at 90° (Fig.10). The diagnosis of condylar mobility was made by measuring the location of the top of the condyle in maximal mouth-open images.

**Hypomobility or limitation of the condyle.** If the top of the condyle was located in 0°-90° (<90°), hypomobility or limitation of the condyle was diagnosed. In this region, the condyle did not translate or translated only slightly (<30°), or translated but did not reach the top of the eminence (<90°) (Fig.10A).

**Normal motion of the condyle.** If the top of the condyle was located in 90°-120° of the eminence, the mobility of the condyle was considered to be normal (Fig.10B).

**Hypermobility of the condyle.** When the condyle translated excessively, beyond and superior to the level of the articular eminence (>120°) (moved more than 30° from the top of the eminence), hypermobility of the condyle could be defined (Fig.10C).

This measurement was performed according to the principles of the standards of Benito et al. (1998) and the standards of Boering, applied by Dijkstra et al. (1993).

### 4.4 Statistical methods

The SPSS software (10.0) was used in statistical analyses. Pearson’s chi-square test was used to analyze the visibility of LPM in MRI with different projections (Paper I) and to analyze the correlations between the pathological findings of the LPM with clinical symptoms, disc displacements and other MRI abnormalities (Papers II, III, IV). Fisher’s exact test (when the expected values were small) was applied in analysis of the relationships between each subgroup of pathological changes of the LPM in patients with TMD (Paper II, III, IV). Nonparametric goodness-of-fit Chi-square test was used to compare frequent differences of the abnormal findings in different bellies of the LPM (Paper II). A probability value (P) of less than 0.05 was considered a significance difference.
5 Results

5.1 Visibility of LPM in MRI

The visible rate of the LPM on sagittal and CLPM imaging of TMJ is presented in Paper I (Tables 1 and 2 in Paper I). The results indicated that the visible rate of the LPM on sagittal images was significantly affected by the degree of mouth opening and the location of the imaging plane. CLPM images could show the LPM constantly. In 325 patients (650 TMJs), the visibility of the LPM on 580 oblique sagittal images, 274 sagittal images and 92 CLPM images of TMJ was compared (Table 1). In 102 patients (204 TMJs) both sagittal and oblique sagittal images were taken. In 46 patients (92 TMJs) both CLPM and oblique sagittal images were taken. The clear visible rates of the LPM in different projections, with the two bellies being clearly observed (Fig.2), are presented in Table 2. It showed that the clear visible rate of the LPM was significantly higher in CLPM images (100% 92/92) and oblique sagittal images (74.5%, 432/580) than in sagittal images (27.8%, 76/274). The very significant differences (P<0.001, Pearson Chi-square test) were found between each group (Table 2).

Table 1. Visibility of LPM in MRI with Different Projections

<table>
<thead>
<tr>
<th>Projections</th>
<th>V2</th>
<th>V1</th>
<th>V0</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLPM</td>
<td>92</td>
<td>0</td>
<td>0</td>
<td>92</td>
</tr>
<tr>
<td>Oblique Sagittal</td>
<td>432</td>
<td>98</td>
<td>50</td>
<td>580</td>
</tr>
<tr>
<td>Sagittal</td>
<td>76</td>
<td>39</td>
<td>159</td>
<td>274</td>
</tr>
<tr>
<td>Total</td>
<td>600</td>
<td>137</td>
<td>209</td>
<td>946</td>
</tr>
</tbody>
</table>

LPM= lateral pterygoid muscle; CLPM= condyle-LPM projection; V2= both bellies can be observed on image; V1= only one belly can be seen in image; V0= non-belly can be seen in image. P<0.001 Pearson Chi-square test (df=4).
Table 2. Clear Visible Rate of the LPM in MRI with Different Projections

<table>
<thead>
<tr>
<th>Projections</th>
<th>V2-Rate %</th>
<th>X²</th>
<th>Sagittal</th>
<th>Oblique Sagittal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLPM</td>
<td>100 (92/92)</td>
<td>144.835***</td>
<td>30.106***</td>
<td></td>
</tr>
<tr>
<td>Oblique Sagittal</td>
<td>74.5 (432/580)</td>
<td>254.806***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sagittal</td>
<td>27.8 (76/274)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

LPM= lateral pterygoid muscle; CLPM= condyle-LPM projection; V2= both bellies can be observed on image; X²= Pearson Chi-square value. ***P<0.001.

5.2 MRI findings of the LPM in patients with TMD

In 650 TMJs of 325 patients in this study, the LPM was clearly observed in 470 TMJs. Normal imaging of the LPM was found in 28.3% (133/470) TMJs. Abnormal imaging of the LPM was found in 71.7% (337/470) TMJs (Table 3).

Abnormal findings of the LPM included hypertrophy (Fig.4 and 6), atrophy (Fig.5, 7 and 8) and contracture (Fig. 7 and 8). Pathological changes were found in either superior belly or in inferior belly, or both. In 35.7% (168/470) TMJs, pathological changes of the superior belly (hypertrophy, atrophy or contracture) was found. Hypertrophy of the inferior belly combined with hypertrophy or atrophy of the superior belly was observed in 26.0% (122/470) TMJs. Abnormal MRI findings only in inferior belly (7%, 33/470) were relative rarely observed. The similar results were found in patients either with symptomatic TMJ hypermobility (Paper II) or with ADDnr (Paper III).
Table 3. MRI Findings of the LPM in 470 TMJs

<table>
<thead>
<tr>
<th>Findings of LPM on MRI</th>
<th>N=470 (100%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>133 (28.3%)</td>
</tr>
<tr>
<td>SLP abnormal</td>
<td>168 (35.7%)</td>
</tr>
<tr>
<td>SLP hypertrophy</td>
<td>93</td>
</tr>
<tr>
<td>SLP atrophy</td>
<td>57</td>
</tr>
<tr>
<td>SLP contracture</td>
<td>18</td>
</tr>
<tr>
<td>ILP Abnormal</td>
<td>33 (7.0%)</td>
</tr>
<tr>
<td>ILP Hypertrophy</td>
<td>24</td>
</tr>
<tr>
<td>ILP Contracture</td>
<td>9</td>
</tr>
<tr>
<td>Two bellies abnormal</td>
<td>136 (28.9%)</td>
</tr>
<tr>
<td>Hypertrophy of SLP and ILP</td>
<td>70</td>
</tr>
<tr>
<td>SLP atrophy with ILP hypertrophy</td>
<td>37</td>
</tr>
<tr>
<td>SLP contracture with ILP hypertrophy</td>
<td>15</td>
</tr>
<tr>
<td>SLP atrophy with ILP atrophy</td>
<td>2</td>
</tr>
<tr>
<td>SLP contracture with ILP atrophy</td>
<td>8</td>
</tr>
<tr>
<td>SLP contracture with ILP contracture</td>
<td>2</td>
</tr>
</tbody>
</table>

LPM = lateral pterygoid muscle; TMJ = Temporomandibular joint, SLP= Superior belly of the LPM; ILP= Inferior belly of the LPM

The relationship between the imaging findings of the LPM in MRI and sex and age of the patients was presented in Tables 4 and 5. Normal and different abnormal MRI findings of the LPM had no significant association with sex (P=0.410>0.05, df=3, Pearson Chi-square test, Table 4) or in different age groups (P=0.710>0.05, df=15, Pearson Chi-square test, Table 5).

Table 4. The Relationship between Sex and Imaging finding of LPM

<table>
<thead>
<tr>
<th>Normal</th>
<th>Hypertrophy a</th>
<th>A,C &amp; H b</th>
<th>A,C c</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>92</td>
<td>139</td>
<td>41</td>
<td>67</td>
</tr>
<tr>
<td>Male</td>
<td>41</td>
<td>48</td>
<td>11</td>
<td>31</td>
</tr>
<tr>
<td>Total</td>
<td>133</td>
<td>187</td>
<td>52</td>
<td>98</td>
</tr>
</tbody>
</table>

LPM= lateral pterygoid muscle; Normal=LPM shows normal in image
a Hypertrophy = hypertrophy of superior or inferior or both bellies.
b A,C & H = atrophy or contracture of superior and hypertrophy of inferior belly
c A, C = Atrophy or contracture of superior or inferior or both bellies ;
Pearson Chi-square test: P=0.410>0.05
Table 5. The Relationship between age and Imaging finding of LPM

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Normal</th>
<th>Hypertrophy a</th>
<th>A,C &amp; H b</th>
<th>A,C c</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20 yrs</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>20-30 yrs</td>
<td>15</td>
<td>21</td>
<td>4</td>
<td>8</td>
<td>48</td>
</tr>
<tr>
<td>30-40 yrs</td>
<td>28</td>
<td>45</td>
<td>12</td>
<td>20</td>
<td>105</td>
</tr>
<tr>
<td>40-50 yrs</td>
<td>35</td>
<td>55</td>
<td>20</td>
<td>29</td>
<td>139</td>
</tr>
<tr>
<td>50-60 yrs</td>
<td>30</td>
<td>32</td>
<td>12</td>
<td>24</td>
<td>98</td>
</tr>
<tr>
<td>&gt;60 yrs</td>
<td>21</td>
<td>29</td>
<td>2</td>
<td>16</td>
<td>68</td>
</tr>
<tr>
<td>Total</td>
<td>133</td>
<td>187</td>
<td>52</td>
<td>98</td>
<td>470</td>
</tr>
</tbody>
</table>

LPM= lateral pterygoid muscle; Normal=LPM shows normal in image
*a Hypertrophy = hypertrophy of superior or inferior or both bellies.
*b A,C & H b = atrophy or contracture of superior and hypertrophy of inferior belly
*c A, C = Atrophy or contracture of superior or inferior or both bellies ; Pearson Chi-square test: P=0.710>0.05

5.3 MRI findings of the LPM and clinical symptoms

The relationships between MRI findings of the LPM and clinical symptoms in 470 TMJs are presented in Table 6. The abnormal findings of the LPM in MRI showed very significant association with the main clinical symptoms of TMD, i.e. jaw restricted movement, palpation pain on TMJ, palpation pain of the LPM and pain in jaw movement (P<0.001, Pearson Chi-square test).

The close association between pathological changes of the LPM and clinical symptoms were also found in patients with symptomatic condyle hypermobility (Paper II) and in patients with ADDnr (Paper III).
Table 6. MRI Findings of LPM in and Clinical Symptoms of Patients with TMD

<table>
<thead>
<tr>
<th></th>
<th>LPMan (n = 337)</th>
<th>LPMn (n =133)</th>
<th>Total (N=470)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TMJ clicking</td>
<td>178</td>
<td>62</td>
<td>240</td>
<td>0.226</td>
</tr>
<tr>
<td>Non-clicking</td>
<td>159</td>
<td>71</td>
<td>230</td>
<td></td>
</tr>
<tr>
<td>TMJ locking</td>
<td>75</td>
<td>34</td>
<td>109</td>
<td>0.444</td>
</tr>
<tr>
<td>Non-locking</td>
<td>262</td>
<td>99</td>
<td>361</td>
<td></td>
</tr>
<tr>
<td>Jaw restricted movement</td>
<td>130</td>
<td>20</td>
<td>150</td>
<td>0.001***</td>
</tr>
<tr>
<td>Non-restricted movement</td>
<td>207</td>
<td>113</td>
<td>320</td>
<td></td>
</tr>
<tr>
<td>Pain in TMJ</td>
<td>218</td>
<td>33</td>
<td>251</td>
<td>0.001***</td>
</tr>
<tr>
<td>Non-pain in TMJ</td>
<td>119</td>
<td>100</td>
<td>219</td>
<td></td>
</tr>
<tr>
<td>Pain in LPM</td>
<td>230</td>
<td>34</td>
<td>264</td>
<td>0.001***</td>
</tr>
<tr>
<td>Non-pain in LPM</td>
<td>107</td>
<td>99</td>
<td>206</td>
<td></td>
</tr>
<tr>
<td>Pain in jaw moving</td>
<td>205</td>
<td>32</td>
<td>237</td>
<td>0.001***</td>
</tr>
<tr>
<td>Non-pain in jaw moving</td>
<td>132</td>
<td>101</td>
<td>233</td>
<td></td>
</tr>
<tr>
<td>Pain in other MM</td>
<td>151</td>
<td>55</td>
<td>206</td>
<td>0.497</td>
</tr>
<tr>
<td>Non-pain in other MM</td>
<td>186</td>
<td>78</td>
<td>264</td>
<td></td>
</tr>
</tbody>
</table>

LPM=Lateral pterygoid muscle; TMJ=Temporomandibular joint; TMD=Temporomandibular disorders; LPMn=LPM shows normally in MRI; LPMan=LPM shows abnormally in MRI; MM=masticatory muscles. Pearson Chi-square test: Significant level at P< 0.05. Very significant level at P<0.001.

5.4 Imaging findings of the LPM, disc position and condyle mobility in MRI

The relationship between LPM with normal or abnormal MRI findings and disc positions is presented in Table 7. Normal and abnormal MRI findings of the LPM exhibited no significant difference in TMJs with or without disc displacements (P=0.082, Pearson’s Chi-square test, df=2). Abnormal imaging of the LPM could be observed in TMJs with disc in normal position (66.7%, 142/213)(Fig.11A) as well as in TMJs with ADDr (76.9%, 103/134) or ADDnr (74.8%, 92/123).
Table 7. MRI Findings of LPM and Disc Position in Patients with TMD

<table>
<thead>
<tr>
<th></th>
<th>NP</th>
<th>ADDr</th>
<th>ADDnr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPMn</td>
<td>71</td>
<td>31</td>
<td>31</td>
<td>133</td>
</tr>
<tr>
<td>LPMan</td>
<td>142</td>
<td>103</td>
<td>92</td>
<td>337</td>
</tr>
<tr>
<td>Total</td>
<td>213</td>
<td>134</td>
<td>123</td>
<td>470</td>
</tr>
</tbody>
</table>

LPM = lateral pterygoid muscle, TMJ = Temporomandibular joint, NP=disc in normal position; ADDr= Anterior disc displacement with reduction, ADDnr= Anterior disc displacement with non-reduction, LPMn = the LPM shows normal in MRI, LPMan = the LPM shows abnormal in MRI, Pearson’s Chi-Square test, P=0.082>0.05

Noticeable, normal imaging of the LPM could be found in 39.4% TMJs with disc displacement, even in some TMJs with severe osteoarthritic changes (Fig.11B).

In order to analyze the possible reason which might lead to pathological changes of the LPM in TMJs with disc in normal position,-the relationship between disc position and condyle mobility in MRI was investigated. The results are presented in Table 8. Condyle hypermobility was mostly found in TMJs with disc in normal position (57.2%, 91/159). Condyle hypomobility was significantly more observed in TMJs with ADDnr (41.8%, 66/158)(P<0.001, Pearson’s Chi-square test).

Table 8. Disc Position and Condyle Mobility in MRI in Patients with TMD

<table>
<thead>
<tr>
<th></th>
<th>NP</th>
<th>ADDr</th>
<th>ADDnr</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypomobility</td>
<td>50</td>
<td>42</td>
<td>66***</td>
<td>158</td>
</tr>
<tr>
<td>Normal mobility</td>
<td>72</td>
<td>36</td>
<td>45</td>
<td>153</td>
</tr>
<tr>
<td>Hypermobility</td>
<td>91***</td>
<td>56</td>
<td>12</td>
<td>159</td>
</tr>
<tr>
<td>Total</td>
<td>213</td>
<td>134</td>
<td>123</td>
<td>470</td>
</tr>
</tbody>
</table>

LPM = lateral pterygoid muscle; TMJ = Temporomandibular joint, NP=disc in normal position; ADDr= Anterior disc displacement with reduction, ADDnr= Anterior disc displacement with non-reduction, Pearson’s Chi-Square test, ***P<0.001

The clinical symptoms and disc position of the patients with symptomatic TMJ hypermobility were studied in Paper IV. Clinical symptoms of TMD were found in TMJs either with disc in normal position or with disc displacement (Table 1 in Paper IV). Palpation pain of the LPM was significantly associated with the clinical symptoms in the TMJs without disc displacements (52.2%, 48/92) (P<0.001, Pearson Chi-square test, Table 2 in Paper IV).
5.5 Pathological changes of the LPM in different types of TMD

5.5.1 Pathological changes of the LPM in TMJ hypermobility

Similar to all TMD patients of this work (Table 3), the TMJ-hypermobility group (Table 4 in Paper II) showed significantly more frequently MRI abnormalities in the superior than in the inferior belly of the LPM (P<0.001, Nonparametric goodness-of-fit Chi-square test). Comparing with other pathological findings, hypertrophy was significantly more often observed in the superior belly (54.9%, 28/51) (P=0.012<0.05, Fisher’s Exact test). In TMJs with MRI pathological findings in both bellies of the LPM (Table 5 in Paper II), hypertrophy of the inferior belly combined with various pathological changes of the superior belly (89.4%, 42/47) was observed significantly more often found in MRI than other abnormal findings (P=0.020, Fisher’s Exact test).

In patients with condyle hypermobility, abnormal MRI findings of the LPM were very significantly more often observed in TMJs with normal-positioned disc than in TMJs with ADDr or ADDnr (P=0.005, Fisher’s Exact test, Table 2 in Paper II). Abnormalities of the LPM in MRI were significantly higher in the symptomatic group of patients (P=0.001, Pearson Chi-square test, Table 3 in Paper II).

These results (Tables 2 and 3 in Paper II) indicated that pathological changes of the LPM might act as a main factor leading to the clinical symptoms in the TMJs without disc displacements in patients with condyle hypermobility.

5.5.2 Pathological changes of the LPM in TMJs with ADDnr

The relationships among the MRI findings of the LPM with other imaging abnormalities on MRI of TMJs with ADDnr are presented in Table 9. MRI findings of the LPM in MRI showed no significant associations with condylar osteoarthritic changes, TMJ effusions or disc deformities, but they did show a highly significant association with condyle mobility (P=0.008, Fisher’s Exact test). The proportion of the pathological findings of the LPM was significantly lower in TMJs with ADDnr in the condylar hypomobility group (63.6%, 42/66) than in the condylar hypermobility (83.3%, 10/12) and the condylar normal motion groups (88.9%, 40/45).
Table 9. The Relationship between Pathological Changes of the LPM and other MRI Findings of 123 with ADDnr

<table>
<thead>
<tr>
<th></th>
<th>LPMan (n = 92)(74.8%)</th>
<th>LPMn (n = 31)(25.2%)</th>
<th>Total (N=123)(100%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteoarthritis</td>
<td>52 (76.5%)</td>
<td>16</td>
<td>68</td>
<td>0.634</td>
</tr>
<tr>
<td>Osteoarthritis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-osteoarthritis</td>
<td>40 (72.7%)</td>
<td>15</td>
<td>55</td>
<td></td>
</tr>
<tr>
<td>Condyle mobility</td>
<td></td>
<td></td>
<td></td>
<td><em>0.008</em>**</td>
</tr>
<tr>
<td>Hypomobility</td>
<td>42 (63.6%)</td>
<td>24</td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>Hypermobility</td>
<td>10 (83.3%)</td>
<td>2</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>40 (88.9%)</td>
<td>5</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Disc deformity</td>
<td></td>
<td></td>
<td></td>
<td>0.414</td>
</tr>
<tr>
<td>Disc deformity</td>
<td>31 (79.5%)</td>
<td>8</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>Non-disc deformity</td>
<td>61 (72.6%)</td>
<td>23</td>
<td>84</td>
<td></td>
</tr>
<tr>
<td>Effusion</td>
<td></td>
<td></td>
<td></td>
<td>*0.711</td>
</tr>
<tr>
<td>TMJ compartment</td>
<td>12 (70.6%)</td>
<td>5</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Bilaminar zone</td>
<td>25 (73.5%)</td>
<td>9</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>TMJ &amp; bilaminar zone</td>
<td>17 (85.0%)</td>
<td>3</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Non-effusion</td>
<td>38 (73.0%)</td>
<td>14</td>
<td>52</td>
<td></td>
</tr>
</tbody>
</table>

LPM= Lateral pterygoid muscle, TMJ= Temporomandibular joint, ADDnr= Anterior disc displacement with non-reduction, LPMan= LPM shows abnormally in MRI, LPMn= LPM shows normally in MRI, % (Show proportion of the LPM abnormality in each imaging finding) =LPMan/Total, Significant level base on Pearson Chi-square test or Fisher’s Exact test. *Very significant level at P<0.01.

As an etiological analysis for condylar hypomobility in TMJs with ADDnr, the relationships among condyle mobility and other MRI findings were summarized (Table 4 in Paper III). The osteoarthritic changes of the condyle were found to be significantly associated with the hypomobility of the condyle in TMJs with ADDnr (P=0.004, Pearson Chi-square test).
6 Discussion

6.1 Methodological considerations

6.1.1 Subjects

The study was based on 353 patients with signs and symptoms of TMD diagnosed in the Department of Prosthetic Dentistry and Stomatognathic Physiology and the Department of Oral and Maxillofacial Surgery between 1989 and 2002. Information concerning patients with TMD was recorded in the specially planned study form. Case histories of the patients were reliable, written in the files by senior lectures and/or specialists in prosthetic dentistry of oral and maxillofacial surgery.

Clinical examinations for all the patients and volunteers in Paper I were made by the author and another experienced clinician (M.H.). A specialist in radiology (X.H. H.) and the author made MRI diagnoses on the patients. All the information of the patients and images was rechecked by another experienced clinician (A.D.) and final analysis of the materials was finished in the Departments of Head & Neck Surgery, University of Leuven, Belgium.

The analyses in Papers II, III and IV were based on retrospective material and the information concerning TMD was collected from patient files at the Department of Prosthetic Dentistry and Stomatognathic Physiology, Institute of Dentistry, University of Oulu. The author has collected and analyzed all patient files and MR images with experienced clinicians (A.M.R. and P.T.).

The weakness of the material part of the study was the small number of normal volunteers and asymptomatic cases (Papers I and II). Asymptomatic TMJs in the study were selected from the asymptomatic side of the patients (Paper II). However, the focus of the study was to analyze the MRI findings of the LPM in patients with TMD. All the patients had evident clinical symptoms of TMD. The normal imaging of the LPM
found in volunteers was used as the standard to evaluate the normal MRI finding of the LPM in patients with TMD (Paper I, Paper II). For further evaluation of MRI findings of the LPM in normal or asymptomatic TMJs larger samples are needed, selected from asymptomatic populations.

Several TMJ problems could be found in patients with collagen vascular disease or rheumatoid arthritis (Koh et al. 1999) or severe trauma histories, i.e. mandibular or condyle fracture (Thoren et al. 2001). These patients have been excluded from the study. Collagen vascular disease, rheumatoid arthritis or severe trauma might also lead to pathological changes of the masticatory muscles (Schellhas 1989b, Koh et al. 1999).

The main aim of the study was to define MRI findings of the LPM in patients with TMD and to analyze the correlations between these imaging findings and clinical symptoms, not to discuss the etiological factors behind pathological changes in the LPM. For etiological analysis of masticatory muscle disease more factors should be taken into consideration, e.g. general health (Schellhas 1989b, Koh et al. 1999), maxillofacial trauma (Hu et al. 1998), parafunctional oral habits (Sari & Sonmez 2002, Wannam & Agerberg 1986, Mahan et al. 1983), malocclusion (Ai & Yamashita 1992, Liu et al. 2000) and mandibular retrognathia deformity (Harper et al. 1997).

**6.1.2 Methods**

Many studies have shown that MRI is the best method of imaging both the hard and the soft tissues of the TMJ (Harms et al. 1985, Katzberg et al. 1986, Schellhas et al. 1986, Raustia et al. 1995, Brooks et al. 1997, Gibbs et al. 1998). The studies have been well documented in comparing MRI of TMJ with arthrography and CT (Schellhas et al. 1988, Liedberg et al. 1996, Trumpy et al. 1997) and in comparing the MRI findings with anatomical and histological observations (Westesson et al. 1987a,b, Larheim et al. 1999). MR imaging diagnoses concerning disc position, effusion and osteoarthritic changes of TMJ were made at the Diagnostic Radiology Department by radiologists. The author rechecked all the images. The variation between the diagnoses was found to be low.

Normal MRI findings of the LPM (Paper I and II) were based on six volunteers defined by the clinical absence, past or present, of any signs or symptoms of TMD who were examined by the author and other experienced clinicians (H.M. and A.M.R.). Diagnosis of atrophy and contracture of the LPM was based on signal changes of fatty replacement, which can be well identified in MRI (Schellhas 1989b, Benito et al. 1998, Paper II). Hypertrophy of the LPM was diagnosed according to the size and morphological changes of the muscle (Schellhas 1989b, van Spronsen et al. 1989). Variations in size of the muscle between individuals might relate to many factors, including skeletal size, age, sex and general health (Schellhas 1989b, van Spronsen et al. 1991). Side-to-side size and morphological comparing in the same individual has been used in the diagnosis of hypertrophy in the LPM, which can reduce and control the individual differences (Schellhas 1989b, Paper II, Paper III). Normal and abnormal MRI findings of the LPM were detected several times in different sessions by the
author. For some parts of the images normal and abnormal MRI findings of the LPM were examined by other clinicians (J.P., A.M.R., and H.P.). Inter-and intra-observer errors were not calculated, but the results indicate that these errors were rather small.

TMJ hypermobility is over-movement of the condyle during jaw opening (Katzberg et al. 1982, Dijkstra et al. 1993). In previous studies, TMJ hypermobility was diagnosed according to measurement of maximal mouth opening range (Winocur et al. 2000, Westling et al. 1992), plain film radiography (Dijkstra et al. 1993), tomography (Katzberg et al. 1982) and MRI (Benito et al. 1998). Axiography and sonography have also been reported in diagnosis of TMJ hypermobility (Piehslinger et al. 1995, Bernhardt et al. 1999, Landes et al. 2000). MRI is considered to be an accurate method for diagnosing condyle mobility and it has been used as an evaluating standard for other methods (Benito et al. 1998, Piehslinger et al. 1995, Bernhardt et al. 1999, Landes et al. 2000). All the patients of this study had undergone MRI for diagnosis of TMD. Condyle mobility can be well identified in MR images of these patients, i.e. hypomobility, normal motion and hypermobility (Fig.3) (Paper II and III). In order to diagnose condyle mobility correctly, the patients were asked to open their mouths as wide as possible when mouth-open images were taken. A mouth-opener was used to fix mouth in maximal open position.

The studies in Paper II, III and IV were based on retrospective material traced back to 1991. Intraoral palpation of the inferior belly of the LPM was still the method used to evaluate palpation pain of the LPM. This method has been applied in many studies (Schwartz & Chayes 1966, Campbell et al. 1982, Wannan & Agerberg 1986, Sindet-Pedersen 1988, Ai & Yamashita 1992, Molina et al. 2000, Liu et al. 2000), although some authors suspect that this method might give an unreliable evaluation (Johnstone & Templeton 1980, Stratman et al. 2000, Turp & Minagi 2001). Functional manipulation or provocation of the LPM has been suggested to replace the intraoral palpation method (Thomas et al. 1987, Stratman et al. 2000). Functional manipulation of the LPM was a method to estimate the pain symptoms, which might be related to the LPM by functional provocation rather than direct palpation (Thomas et al. 1987). The result of the study found that the MRI abnormal findings of the LPM showed a close association with palpation pain of the muscle (Paper II, III and IV). Whether functional provocation could be a better method in evaluating pathological situations of the LPM than palpation of the muscle could not be discussed in this study. However, MRI findings of the LPM might provide further useful imaging evidence for comparing these two methods in the future.

### 6.2 Visibility of the LPM in MRI

The main aim of the study reported here was to explore MRI findings of the LPM in patients with TMD. For this purpose, the first thing was to find out whether the LPM could be shown clearly and constantly on the images. Previous studies had discussed some normal and abnormal imaging findings of the LPM in sagittal or oblique sagittal MR images (Katzberg et al. 1985, Schellhas 1989ab, Benito et al. 1998), but another
study reported that the findings of the LPM were not constant on the images (Schellhas 1989). The present study found that the visibility of the LPM was evidently affected by different imaging projections, location of imaging layers and different jaw positions (Table 1 and 2 in Paper I).

In order to diagnose pathological changes in the superior or inferior belly of the LPM, it was necessary to observe both bellies clearly on the images. Anatomical studies of the LPM have reported that the anterior part of the two bellies are separated by a space, or gap, which is filled by fibrous and adipose tissue and usually contains the maxillary artery, but the two bellies blend, or fuse, together near the insertion (Sicher 1965, Wilkinson 1988, Schmolke 1994, Bittar et al. 1994, Fujita et al. 2001). Imaging of the LPM in present study agreed with these anatomical findings (Fig.2A, Fig.4). The two bellies could be well identified on the image with the anterior gap between the two bellies. This gap between was near the origin side of the LPM (Fig.2A, Fig.4). When this gap was observed, it indicated that the most part of the LPM had been shown on the image and the image was suitable for diagnosis of morphological and signal intensity changes for each belly (Fig.2A). Oppositely, if only the insertion part of the LPM was shown on the images, the two bellies could not be separately identified. The evaluation of the LPM could not be made according to these images (Fig.2 B and C).

Clear visible rate of the LPM with two bellies observed in MRI was significantly higher in CLPM (100%, 92/92) and oblique sagittal images (74.5%, 432/580) than in sagittal images (27.8%, 76/274)(Table 2). The long axis of the LPM running angularly to the sagittal plane was considered to be the main reason behind these differences (Quemar et al. 1993, Paper I). The angle between the long axis of the LPM and sagittal or oblique sagittal plane could be observed clearly on cross-section imaging (Fig.1 A and B). When the angle became smaller, the trend of scanning plane was towards parallel to the long axis of the LPM, and more parts of the muscle could be scanned (Fig. 1), the better the visibility of the muscle on the images that might be obtained. The oblique sagittal scanning plane was nearer to the parallel sections of the long axis of LPM than the true sagittal plane (Fig.1 A and B). In CLPM projection the angle between the long axis of the LPM and scanning became zero (Fig.1C). It seemed that the CLPM and oblique sagittal images of TMJ was suitable for evaluating the LPM.

In some studies axial cross-section and coronal planes have been applied in MRI to investigate the masticatory muscles, including the LPM (Kahl-Nieke & Fischbach 1999, van Spronsen et al. 1989, van Spronsen et al. 1991).

The axial cross-sectional and coronal plane are nearly perpendicular or parallel to the long axis of the masseter muscle, temporal muscle and medial pterygoid muscle, but the LPM runs angular to these planes. On axial cross-sectional imaging, the location and the running direction of the main fibers of the LPM can be observed (Paper I, Quemar et al. 1993). However, only the upper part of the superior belly was shown on the image (Fig.1). For this reason, the axial cross-section image may be not suitable for detecting the imaging abnormalities in both bellies of the LPM. The LPM runs from the origins to the insertion with a fan shape (Paper I, Quemar et al. 1993, van Spronsen et al. 1989).

Coronal or oblique coronal imaging planes are near to the cross-section plane of the LPM (van Spronsen et al 1989, Gibbs et al. 1998). van Spronsen et al. pointed out that
for a fan-shaped muscle, such as the temporal muscle and the LPM, a small shift of the scanning plane might result in a considerable change in areas, or size, of the muscle in cross-section imaging, so these muscles are more susceptible to scan or patient-positioning errors in cross-section scanning (van Spronsen et al. 1989). Other authors have excluded the cross-section imaging of the temporal muscle and the LPM from their study, because it is possible to make false evaluations (Hannam & Wood 1989). Neither coronal nor axial cross-sectional imaging of TMJ can show the relationship between the LPM and the disc. However, CLPM and oblique sagittal images of TMJ can show the condyle, disc and the LPM in the same image.

The imaging diagnoses of the LPM in this study were based on images with the two bellies clearly and in mouth-closed position. In mouth opening images, the length and width of the LPM is altered, which may affect the morphological evaluation of the muscle (Paper I, Quemar et al. 1993). The morphological characteristics of the LPM in mouth-open imaging need further researches in future.

6.3 Pathological changes of the LPM and clinical symptoms of TMD

In the studies reported here, different types of imaging pathological changes in LPM were found in patients with TMD, i.e. hypertrophy (Fig.5), atrophy (Fig.6,7,8) and contracture (Fig.8,9). These pathological changes were found in the superior belly, inferior belly or both (Table 3). The MRI abnormal imaging of the LPM might be found in either male or female or in different ages groups of the patients with TMD (Tables 4 and 5).

In studies of other skeletal muscles, the MR imaging abnormalities of the muscles have been reported associated with chronic pain symptoms in the leg, back and shoulder, possibly leading to abnormal and dysfunctional movements of the related joints (Bertorini et al. 1994, Jacobs et al. 1994, Chen et al. 1998, Thyagarajan et al. 1998, Katz & Ropper 2000, Kader et al. 2000). These pathological changes and clinical symptoms are in some way similar to TMD.

In an anatomical study on autopsy specimens, Schmidt et al. (1998) observed that the single trunk of the auriculotemporal nerve was evident along the medial aspect of the condylar neck and was in direct contact with the condylar neck at the posterior border of the LPM. The anteriorly dislocated disc and displaced capsular tissue were considered to produce nerve irritation and to cause painful symptoms. In addition, the authors proposed that hypertrophy of the LPM might also lead to entrapment or compression of the nerve. However, in their study hypertrophy of the LPM was only expected, but not being proved (Schmidt et al. 1998). In the studies reported here, hypertrophy of the LPM was observed in MRI in patients with TMD (Fig.5,7)(Table 3).

When analyzing the relationship between atrophy and contracture of the LPM in MRI and clinical symptoms of TMD, Schellhas (1989b) reported that atrophy and contracture of the muscle might lead to painful symptoms in the muscles, abnormal
joint movements and pain on TMJ movement, which might be considered pain-induced reflex sympathetic dystrophy.

The results of these earlier studies (Schellhas 1989, Schmidt et al. 1998) agreed with the present findings that pathological changes of the LPM in MRI were associated with main symptoms of TMD (Table 6). It indicates that patients might complain of these symptoms when pathological changes of the LPM are observed in MRI.

6.4 Pathological changes of the LPM in different types of TMD

6.4.1 Pathological changes of the LPM and disc displacements

Excessive exercise, overloading, abnormal stretching (Bertorini et al. 1994), minor trauma (Thyagarajan et al. 1998), and denervation disease (Petersilge et al. 1995) have been mentioned as possible factors contributing to muscle hypertrophy. Atrophy and contracture of the muscles have generally been considered to be caused by disuse and denervation (Thyagarajan et al. 1998). Collagen vascular disease or rheumatoid arthritis may also affect masticatory muscles (Koh et al. 1999). If patients have no history of severe trauma, collagen vascular disease, debilitating diseases or denervation disease, atrophy or contracture of muscles are considered to be the secondary changes of excessive muscle activity, stretching and work overload (Thyagarajan et al. 1998, Kader et al. 2000). This was most likely the situation of the patients with TMD in this study.

The pathological changes of the LPM in TMD need to be discussed on the basis of the function of LPM. The functional activity of LPM is not fully understood, but most EMG studies support the notion that the superior belly of the LPM is active during jaw closing and clenching movements to act against biting force and to stabilize the relationship between the condyle and the disc. The inferior belly of the LPM is active during mouth opening, protrusion of the mandible, and movement of the mandible to the contralateral side (Mahan et al. 1983, Lafreniere et al. 1997, Hiraba et al. 2000). In case of excessive exercise, overloading or minor trauma in functional activities of the LPM, pathological changes of the muscle may occur.

Farrar and McCarty described micro- and macrotrauma in internal derangement of TMJ (Farrar and McCarty 1979). The abnormal disc-condyle relationship was regarded as the factor leading to traumas and damage of TMJ structures (Farrar and McCarty 1979, Farrar 1971). Many studies have found abnormal positions of the disc to be associated with disc deformities (Yoshida et al. 2000, Taskaya-Yilmaz & Ogutcu-Toller 2001), disc degenerative changes (Widmalm et al. 1992, Kondoh et al. 1998) and osseous changes of the condyle (Westesson 1985, Kurita et al. 2000, Bertram et al. 2001). The abnormal relationship between disc and condyle is considered to be associated with pain symptoms in TMD (Emshoff et al. 2001). The results of these studies indicate that disc displacement may lead to abnormal and unstable condyle-disc relationships in jaw movements. Under this situation, the superior belly of the LPM has to work excessively to keep the relationship between condyle and disc stable.
(Lafreniere et al. 1997). Excessive work or overloading may lead to hypertrophy and secondary atrophy or contracture of the muscle. It can explain the findings of this study that imaging abnormalities of the LPM were found in 76.8% (103/134) TMJs with ADDr and 74.8% (92/123) TMJs with ADDnr (Table 7). It may also explain the finding of this study that pathological changes of the superior belly of the LPM were more often observed than other imaging abnormalities in MRI in the patients with disc displacements (Table 1 in Paper III).

However, imaging abnormalities of the LPM were not only found in TMJs with disc displacements but also in 66.7% (142/213) TMJs with disc in normal position in the material of this study (Fig. 11A). There is no significant difference between the distribution of pathological changes of the LPM in TMJs with or without disc displacements (Table 7). Obviously, disc displacements cannot explain pathological changes of the LPM and possible related symptoms in TMJs with the disc in normal position.

6.4.2 Symptoms of the LPM in TMJs with disc in normal position

TMD symptoms in TMJs with disc in normal position have been noticed in some other studies (Müller-Leisse et al. 1996, Benito et al. 1998, Bernhardt et al. 1999, Emshoff et al. 2001). The prevalence of TMJs with clinical symptoms but with normally positioned disc was 10.2% to 19% in these studies. Benito et al. (1998) have analyzed the relationships between the clinical symptoms of TMD, disc movement and condyle translation by MRI. The study found that pain symptoms of TMJ with or without disc displacements might relate to static disc during the jaw movements. However, normal positioned discs with static in movement were rare (Benito et al. 1998).

Abnormal translations of the condyle, either hypomobility or hypermobility, have been discussed as the important factor that may be related to the symptoms of TMD in many studies (Katzberg et al. 1982, Westling 1989, Bernhardt et al. 1999, Landes et al. 2000). TMJ hypermobility is regarded as a subgroup diagnosis in early stage of TMD (Wilkes 1989, McNeill et al. 1990). Katzberg et al. (1982) investigated 102 TMJs with internal derangements by arthrotomography and found that in 28 patients who had ADDr with painful clicking they were combined with condyle hypermobility. Other reports have also considered TMJ hypermobility to be associated with disc displacements, because the patients experienced clicking or painful clicking (Westling 1989, Westling et al. 1992, Holmlund et al. 1999). The study carried out by Katzberg et al in 1982 was based on patients with internal derangements. TMJs with the disc in normal position might have been excluded from the study. Clicking may not be a reliable sign to determine disc displacements. Some studies have found that the clicking in TMJs with hypermobility might not be associated with disc displacements (Solberg 1986b, Buckingham et al. 1991, Khan & Pedlar 1996). These reports consider that condyle hypermobility may be caused by laxity of capsular structures, and joint laxity may lead to joint clicking even without disc displacements (Solberg 1986b, Khan & Pedlar 1996). It seems that more detailed information is needed in comparing disc
Disc positions and condyle mobility were analyzed in this study (Table 8). In 57.2% (91/159) of TMJs with condyle hypermobility the disc was in normal position, which was observed significantly more frequently than ADDr and ADDnr. The clinical symptoms of TMJs with condyle hypermobility have no significant difference in TMJs with or without disc displacements (Table 1 in Paper IV). It seems that TMJs with disc in normal position may have clinical symptoms as well as the joints with the disc displacements when condyle hypermobility has occurred. Painful clicking was the main symptom of these joints (Table 1 in Paper IV). It was found that in TMJs with disc in normal position the painful symptoms were originated mainly from the LPM (Table 2 in Paper IV). This indicates that hypermobility of the condyle and related pathological changes of the LPM may play important roles leading to clinical symptoms in TMJs with the disc in normal position.

### 6.4.3 Pathological changes of the LPM in TMJ hypermobility

Clinically, different terms have been used to denote TMJ hypermobility, such as recurrent luxation of TMJ (Holmlund et al. 1999), recurrent mandibular dislocation (Undt et al. 1997) or recurrent subluxation of TMJ (Sacks et al. 1990). The most common clinical complaint of symptomatic condyle hypermobility is clicking with painful symptoms related to TMJ and masticatory muscles (Katzberg et al. 1982, Dijkstra et al. 1993, Holmlund et al. 1999). Similar clinical symptoms of TMJs with condylar hypermobility were also found in present study (Papers II and IV).

MRI abnormal findings of the LPM were significantly more often observed in TMJs with disc in normal position (Table 2 in Paper II). The abnormalities of the LPM were also significantly more often found in the TMJs with symptomatic hypermobility (Paper II, Table 3). These findings show that pathological changes of the LPM and condyle hypermobility may play important roles in giving rise to the symptoms in the TMJs with the disc in normal position.

From the etiological point of view, the loose connective tissues and ligaments around joints are considered to lead to TMJ hypermobility as well as generalized joint laxity (Westling 1989, Westling et al. 1990, Sacks et al. 1990, Buckingham et al. 1991, Westling et al. 1992, Winocur et al. 2000). Laxity of the joint structures may destabilize the condyle-disc relationship in TMJ (Dijkstra 1993, Westling et al. 1992). Under this condition, as a possible explanation for the findings of this study, the superior belly of LPM might have an abnormal over-loading in order to keep the structures stable, which might cause excessive exercised hypertrophy of the belly. In an anatomical study of the TMJ, Grunert et al. (2000) noticed that the evident hypertrophy in the superior belly of LPM was observed in some TMJs with normal-positioned disc. He also suspected that hypertrophic changes of the superior belly of LPM might be caused by chronic overloading.
Minor trauma may also cause local muscle hypertrophy, chronic pain and chronic spasms (Thyagarajan et al. 1998). Condyle hypermobility may lead to microtrauma of TMJ (Farrar 1971, Bernhardt et al. 1999). Westling et al. (1990) pointed out that lax joints provide less protection against microtrauma and macrotrauma. The results of anatomical studies show the superior belly of LPM inserting into condyle and the capsule (Wilkinson 1988, Heylings et al. 1995, Naidoo 1996). When the condyle is hypermobilized on mouth opening, the condyle may press the anterior part of the capsule where the insertion of the superior belly of LPM is located (Fig.3c). This pressure might cause a microtrauma directly to the superior belly. From the anatomical point of view, it could be hypothesized that the microtrauma caused by the hypermobilized condyle may also be a possible factor causing hypertrophy of the superior belly of the LPM and associated clinical symptoms.

Prolonged chronic overloading or microtrauma might act as factors causing atrophic changes of the muscle as observed in this study. Atrophy or contracture of muscles is regarded as secondary changes of excessive muscle activity, stretching and work overload when there is no history of disuse after trauma, immobility, debilitating disease or denervation disease involved (Bertorini et al. 1994).

It could be assumed that laxity of the joint structures and possible minor trauma caused by a hypermobile condyle might lead to pathological changes of the LPM, even in TMJs with the disc in normal position (Table 2 in Paper II).

### 6.4.4 Pathological changes in the two bellies of the LPM

Another characteristic feature of pathological changes in the LPM observed in this study was that hypertrophy of the inferior belly combined with various pathological changes of the superior belly of LPM affected both bellies significantly more often than other imaging abnormalities (Table 3). This finding might agree with the result of the EMG study of LPM by Lafreniere et al (1997). They found that EMG activity of the inferior belly was significantly higher when the superior belly of LPM seemed to have lost its disc-stabilizing function. The inferior belly was considered to adapt its function to instead of the hypo-functional superior belly. The excessive work of the inferior belly might occur after the superior belly becomes hypo-functional under chronic overloading and might result in secondary hypertrophy of the inferior belly. This is supported by the present results which show that atrophy or contracture of the superior belly combined with hypertrophy of the inferior belly was found in 38.2% (52/136) of the TMJs with MRI abnormal findings in the two bellies (Table 3).

Unstable movement between condyle and disc, which may be caused by disc displacement or laxity structures, might also directly affect the inferior belly of the LPM. Some histological and anatomical studies on autopsy specimens have found not only the superior belly but also some fibers of the inferior belly inserting into the capsular tissues near the disc (Schmolke 1994, Bittar et al. 1994, Fujita et al. 2001). It has been suggested that both bellies of the LPM may influence, or be influenced by, the stable position of the disc on jaw movements (Schmolke 1994). This means that
unstable relationship between disc and condyle might lead to excessive work of both bellies. In MRI, hypertrophy in both bellies of the LPM has been observed in 51.5% (70/138) TMJs with pathological changes in bellies in this study (Table 3) (Fig.6 in Paper II and Fig.7 in Paper III).

6.4.5 Pathological changes of the LPM in late stage of TMD

In this study, it was found that the pathological MRI changes of the LPM show a close association with symptomatic condyle hypermobility (Table 3 in Paper II). As a comparative analysis, it was worthwhile to investigate the LPM in TMJs with condyle hypomobility. Many studies have reported that hypomobility of the condyle occurs more often in TMJs with ADDnr (Katzberg et al. 1982, Wilkes 1989, Schellhas 1989a, Westesson 1993). This was found in present study also (Table 8).

Many studies have considered ADDnr to be the advanced stage, or late stage of TMD (Katzberg et al. 1982, Wilkes 1989, Schellhas 1989a, Westesson 1993). Condylar osteoarthritic changes, hypomobility of condyle, TMJ effusion and disc deformities were reported as main MR imaging abnormalities in the joints with ADDnr (Westesson et al. 1984, Westesson et al 1985, Kurita et al. 2000, Emshoff et al. 2001, Taskaya-Yilmaz and Ogutcan-Toller 2001). Hypomobility of the condyle has been regarded as a progressive symptom of TMD (Wilkes 1989, Benito et al. 1998, Yoshida et al. 2000). In this study, MRI abnormal findings of the LPM were found in 74.8% (92/123) of TMJs with ADDnr. The present TMJs with ADDnr showed a close association with condyle hypomobility. Interestingly, statistical analysis of this study showed, however, that the proportion of the LPM abnormality was significantly lower in the condylar hypomobility group (Table 9). Moreover, in some cases, although evident osteoarthritic changes and limitation of the condyle were observed, the LPMs showed as normal (Fig. 11B and Figs. 10-12 in Paper III).

Osteoarthritic changes were suspected as a closely associated factor for condyle hypermobility in the study (Table 4 in Paper III). Benito et al. (1998) reported that the movement of disc was poor in TMJ with osteoarthritis. They found that hypomobility of the condyle was significantly associated with the static disc. Adhesion of the disc was suspected. When the possibility of condyle movement becomes poor due to a fixed disc (Benito et al. 1998) or because adhesion has occurred between osteoarthritic bony tissues and disc (Schellhas 1989a, Eberhard et al. 2000), the relationship between the disc and the condyle might become relatively stable. The overloading of the LPM might be reduced because of condylar hypomobility. That may lead to pathological changes of the LPM reduced in TMJs with ADDnr as observed in this study (Table 9). Understandable, the symptoms associated with the LPM could be released. Condylar hypomobility was considered to be a pathway for ADDnr (Wilkes 1989, Westesson 1993), the symptom, especially the symptom concerned with the LPM, probably is possible to be released in the later stage of TMD. This finding may explain the results of other reports that the clinical symptoms may be released in some TMJs with ADDnr.

In this study the MRI abnormal findings of the LPM seemed independent of joint effusion, osteoarthritic changes on the condyle and disc deformities (Table 9). This suggests that osteoarthritic changes, joint effusion and disc deformities may not be improved even if pathological changes and the related symptoms of the LPM had been relieved. These findings provide imaging evidence to verify the results of other studies, which found that the clinical symptoms of TMJs with ADDnr may trend to be relieved with or without treatment, but that disc displacement, disc deformity and osseous changes of the joint do not change (Montgomery et al. 1992, Kurita et al. 1998, Sato et al. 1999, Nishimura et al. 2001). The alteration of the pathological situations in the LPM found in this study may also explain why internal derangement and degenerative changes inside of TMJ shows as a progressive damaging procedure, oppositely, clinical symptoms might show as a chronic, gradually released procedure (Wilkes 1989).
7 General discussion

Since the time Costen (1934) reported this syndrome until now, many aspects in the diagnosis and treatment of TMD have been controversial and continue to be an area for debate. Etiology of TMD is still poorly understood (Sherman and Turk 2001). Although several defined terms are based on different etiology (Costen 1934, Laskin 1969, Thompson 1971, McNeill 1990) similar signs and symptoms are presented, comprising a number of clinical problems that mainly involves two aspects: the masticatory muscles and/or the temporomandibular joint (Westesson 1993).

Within the last 20 years, improvements of imaging methods in TMJ using arthrography and MRI have led to increasingly accurate diagnosis of disc position (Wilkes 1978a, Katzberg et al. 1979, Westesson et al. 1980, Harms et al. 1985, Schellhas et al. 1986). Studies on TMD are in many aspects profound. Disc displacements in TMJ are considered to be factors which may lead to disc deformities, osseous changes and clinical symptoms of TMD (Westesson 1985, Farrar & McCarty 1979, Katzberg et al. 1996, Yoshida et al. 2000, Bertram et al. 2001). These imaging findings have been proved right by surgical observations (Wilkes 1978 a, b, Schellhas 1989a) as well as histological and anatomical studies in autopsy specimens (Westesson & Rohlin 1984, Larheim et al. 1999, Leonardi 2001). All these studies have provided more and more evidence in the diagnosis of TMD. It should be noticed that these studies focus mainly on disc displacements.

In comparison, research on the masticatory muscles concerning TMD is still under development (Helkimo 1974a, b, Solberg 1986a, De Laat 1998, Greene 2001). Among the masticatory muscles, the LPM is considered to play an important role in TMD procedures (Juniper 1984, Lafreniere et al. 1997, Raustia et al. 1998). However, the LPM is a deep located muscle and it is difficult to detect by either clinical examination or EMG (Stratmann et al. 2000, Hiraba et al. 2000). Normal and abnormal functions of the LPM have been discussed in EMG studies, but they still remain unclear (Hiraba et al. 2000). More visible evidence is needed to diagnose pathological changes of the muscle.

Clinical studies concerning the skeletal muscles have shown that MRI is a reliable imaging method for diagnosing muscle diseases (Weinreb et al. 1985, Schellhas 1989a, Schellhas et al. 1986).
The main questions explored in the study reported here are as follows: whether MRI can detect pathological changes of the LPM; what kinds of pathological changes of the LPM may appear in TMD; the characteristics of these pathological changes and associated clinical symptoms. No reports on these appear in previous studies.

The results of this study show that the visibility of the LPM in MRI is influenced by imaging projections (Paper I). Imaging diagnosis of pathological changes of the LPM should be based on images that can show both bellies clearly and be less affected by shifting of the scanning plane. According to the anatomic characteristics of the LPM, the more nearly parallel the scanning plane is to the long axis of the LPM, the clearer the observation of the muscle that can be obtained (Paper I, Quemar et al. 1993). A new imaging projection—CLPM projection for TMJ and the LPM is reported in this study, going through the condyle and parallel to the long axis of the LPM (Paper I). It is able to show the LPM constantly in either mouth closed or mouth opening images (Paper I). It appears that most of the CLPM and oblique sagittal images of TMJ can show the LPM and joint structures clearly. The characteristics of CLPM images need to be discussed with a more extensive patient material in further studies (Paper I, Quemar et al. 1993).

Normal imaging of the LPM, hypertrophy, atrophy and contracture of the muscle in patients with have been described in the studies reported here (Papers I-III). It appears that pathological changes of the superior belly and hypertrophy of the inferior belly combined with various abnormalities of the superior belly are the most frequently findings in the LPM of the patients with TMD (Papers II and III). These findings may provide imaging evidences for diagnosis of pathological changes of the LPM in TMD.

Muscular diseases may lead to pain symptoms, and abnormal functional movements of the related joints have been confirmed in studies concerning the leg, shoulder and back (Bertorini et al. 1994, Jacobs et al. 1994, Chen et al. 1998, Thyagarajan et al. 1998, Katz & Ropper 2000, Kader et al. 2000). Similarly, close associations are found between the imaging abnormalities of the LPM and the clinical symptoms of TMD in the studies reported here (Papers II and III). This indicates that the imaging findings of the LPM may explain the clinical symptoms of TMD and their alterations.

There are two other important findings in this study. One is that condyle hypermobility and related pathological changes of the LPM may play an important role in giving rise to the clinical symptoms in TMJs with disc in normal position (Papers II and IV). The other is that imaging abnormalities of the LPM are significantly reduced in condyle hypomobility cases in TMJs with ADDnr even osteoarthritis and disc deformities may occur in these cases (Paper III). Imaging abnormalities may be found in TMJs with disc in normal position, but normal imaging of the LPM may be observed in TMJs with severe disc displacement, osteoarthritic changes and disc deformity (Fig. 11). These findings may give some imaging evidence for understanding clinical symptoms that cannot be totally explained by disc displacements. The recognition of muscle alterations may lead to a correct diagnosis and improved understanding of the clinical symptomatology and disease pathophysiology under investigation (Schellhas 1989). MRI findings of the LPM may provide more evidence for etiological study of pain symptoms in TMD.
Many treatments have been reported to release muscle pain in TMD, e.g. splint treatment (Dao & Lavigne 1998, Williamson & Rosenzweig 1998), manual therapy (Nicolakis et al. 2001), biofeedback and cognitive-behavioural therapy (Sherman & Turk 2001). However, proof of pathological changes of the masticatory muscles still seem to be lacking in these studies (Nicolakis et al. 2001, Williamson & Rosenzweig 1998). MRI findings of the LPM may offer a useful tool for diagnosis and give important information to evaluate the clinical efficacy of these different treatment procedures.

Obviously, histological confirmation of the imaging pathological findings in the LPM is very important and further research is needed in future.
8 Conclusions

1. CLPM images and most oblique sagittal images of TMJ are able to show two bellies of the LPM more clearly than straight sagittal images and they are recommended to be used in the evaluation of the LPM.

2. In MRI, hypertrophy, atrophy and contracture are found in the LPM of the patients with TMD. Pathological changes of the superior belly and hypertrophy of the inferior belly combined with various pathological changes of the superior belly are the most frequently observed abnormal MRI findings of the LPM in TMD.

3. MRI abnormalities of the LPM show close associations with the main symptoms of TMD, i.e. jaw movement pain, palpation pain in the LPM, restricted jaw movement and palpation pain in TMJ.

4. In patients with TMD, pathological changes of the LPM may be found in TMJs with or without disc displacements. Abnormal MRI findings may be observed in TMJs with disc in normal position. Normal imaging of the LPM can be found in TMJs with disc displacement and severe osteoarthritic changes.

5. In different types of TMD, condyle hypermobility and related pathological changes of the LPM may play an important role in giving rise to the clinical symptoms in TMJs with disc in normal position. Imaging abnormalities of the LPM are significantly reduced in condyle hypomobility related to TMJs with ADDnr, which may explain the improvement of clinical symptoms in these cases.
9 References


10 Appendix: Figures
Fig. 1 MRI projections of TMJ are oriented on axial imaging. The upper part of the superior belly and running direction of the lateral pterygoid muscle (LPM) can be observed.

(A) Axial MR images show orientation of orthogonal sagittal MRI scanning planes. Angle “α” indicates the LPM runs angularly with the scanning plane.

(B) Axial MR images show orientation of oblique sagittal MRI scanning planes. Scanning plane is perpendicular to the long axis of the condyle. Angle “β” shows the angle between the main fibers’ running direction of the LPM and the scanning plane. Comparing (A) and (B), note that β < α. Oblique sagittal scanning planes are nearer to parallel to the long axis of the LPM than orthogonal sagittal scanning.

(C) Axial MR images show orientation of condyle-lateral pterygoid muscle (CLPM) MRI scanning planes. The scanning planes are parallel to the main fibers’ running direction of the LPM. In CLPM projection the angle between the long axis of the LPM and scanning became zero

Note that when the angle between the long axis of the LPM and scanning plane becomes smaller, the trend of scanning plane is towards parallel to the long axis of the LPM, and more parts of the muscle can be scanned.

Fig. 2 Visibility of the LPM in MRI.

(A) Both bellies of the LPM can be observed clearly in MRI, classified as V2. Anterior gap (arrow) between the superior belly (SB) and inferior belly (IB) can be seen. (C=condyle)

(B) Only one belly of the LPM can be observed in MRI, classified as V1. In image B, only superior belly of the LPM (SB) is shown. (C=condyle)

(C) Non-belly or only insertion part of the LPM can be observed in MRI, classified as V0. In image C, anterior displaced disc with deformity is found (arrow), but the LPM cannot be observed. (C=condyle).
Fig. 3 Normal imaging of the LPM obtained from volunteer and asymptomatic TMJs.

(A) Mouth-closed, oblique sagittal, Proton Density (2000/20) (1.5-T magnet) left TMJ image of a 28-year-old male volunteer who had no suspicious clinical signs and symptoms of TMD. The normal LPM structures show as a fan-like muscle from the origins to the neck of the mandibular condyle or disc. A high signal layer of fat tissue separates the superior belly of the LPM (SB) form the inferior belly of the LPM (IB). A high-signal fat layer can be observed between the two bellies (arrow). Near the insertion part of the LPM the two bellies are fused with each other (C=condyle; D=disc).

(B) Normal LPM find in mouth-closed oblique sagittal PD (3000/14) MRI image of left TMJ of a 65-year-old female who has experienced pain on jaw movement and clicking of right but no clinical symptoms on left side. On this image of the left TMJ, the disc is seen in normal position. The superior belly (SB) and inferior belly (IB) of the LPM appear normal. Vessels and fat layer can be observed between the two bellies (arrow) (C=condyle).
Fig. 4 Hypertrophy of superior belly of the LMP shows in images of a 52-year-old female with chronic facial pain, jaw movement pain and TMJ pain on right side for nine years, symptoms released after splint treatment. Left TMJ recurrently painful and restricted in 3 months. Palpation pain of LPM and locking were detected on the left. Palpation pain of temporal muscles was found on both sides. Anterior disc displacement with non-reduction was found in TMJ on both sides in MRI (SB= the superior belly; IB= inferior belly of the LPM; C= condyle).

(A) In mouth-closed image (oblique sagittal, 3000/14, 1.5T, 3-mm-thick) of left TMJ, hypertrophy of the superior belly (SB) of the LPM is suggested by the evidently enlarged size of the belly (compare with the superior belly of the LPM of right TMJ in image B). Disc is anteriorly displaced and deformed (black arrow). Effusion can be found at bilaminar zone (white arrow).

(B) The LPM shows as normal on mouth-closed image of right TMJ (oblique sagittal, 3000/14, 1.5T, 3-mm-thick). The disc shows anterior displacement (arrow). Osteoarthritic change of the condyle can be observed.
Fig. 5 Atrophy of the superior belly of the LPM is found in TMJs either with disc in normal position or with disc displacement (C=condyle; D=disc; IB=inferior belly of the LPM).

(A) Atrophy of the LPM superior belly (arrow) in a 42-year-old female who has had progressing pain in the TMJ, facial and temporal pain on the right side for five years. Palpation pain in the LPM and movement pain in both TMJs associate with painful clicking. The mouth-closed oblique sagittal PD (3000/15) (1.5-T magnet) MRI image of the right TMJ reveals atrophy and fatty replacement in superior belly of the LPM (arrow). Disc (D) appears in normal position. Condyle hypermobility was found in maximal mouth-open imaging of this joint.

(B) Atrophy of the superior belly of the LPM (arrow) is revealed in a 35-year-old female who suffered pain on jaw movement, had difficult in mouth opening as well as facial pain on left TMJ for the past two years. The symptoms could not be improved by splint treatment. Painful locking and severe palpation pain on the LPM are detected on the left side. In mouth-closed, oblique sagittal image of the left TMJ (3000/14, 1.5-T magnet), atrophy of the superior belly of the LPM with large area high signal fatty replacement (arrow) is noted. The inferior belly appears normal. Anterior disc displacement (D) and osteophyte of the condyle (C) are found. The displaced disc cannot reduce in maximal mouth-open image.
Fig.6 Hypertrophy of the inferior belly combined with atrophy of the superior belly of the LPM has been diagnosed by side-to-side comparing in a 41-year-old female with long-term chronic pain on right TMJ for five years with recurrent subluxation. Movement pain, palpation pain of TMJ and masticatory muscles (temporal muscle and LPM) are found on the right side. The mandible is towards the left during mouth opening. No symptoms were found on the left side. Hypermobility of the condyle is found on both sides in maximal mouth open MRI (C= condyle; SB=superior belly; IB = inferior belly).

(A) Normal LPM reveals on mouth-closed image of the left TMJ (oblique sagittal, 3000/20). Anterior gap between the two bellies can be clearly observed (arrow). Disc is in normal position.

(B) Mouth-closed image of the right TMJ (oblique sagittal, 3000/20) shows hypertrophy of inferior belly combined with atrophy of superior belly (arrow) of the LPM. Atrophy shows as high signal fatty replacement in superior belly of the LPM (arrow). Hypertrophy of the inferior belly (IB) is shown as increased size of the belly (compare with the inferior belly of the LPM on the left side in image A). Note the anterior gap between the two bellies might have been occupied by hypertrophic muscular tissue of the inferior belly. The upper edges of the inferior belly become convex curves. Disc is in normal position.
Atrophy and contracture of the LPM is suspected in a 36-year-old female with occasional locking and chronic pain on both TMJs for 5 years, painful on the left side and restricted in jaw movements for 9 months. Symptoms show no evident improvement after splint and muscle exercising treatment. Severe palpation pain of the lateral pterygoid muscle (LPM) is found on both sides, painful on the left. In MRIs, the anterior displacements of disc are found on both sides. The displaced disc shows reducing on the left TMJ and non-reducing on the right.

(A) Atrophy of the superior belly of the LPM is shown in the mouth-closed, oblique sagittal, proton dense image of the right TMJ (3000/14, 1.5-T magnet). High signal fatty replacement tissue can be observed inside the superior belly (white arrow). The inferior belly of the LPM (IB) shows as normal. Disc is anteriorly displaced (black arrow). (C= condyle).

(B) In T2-weighted (3000/125, 1.5-T magnet) image mouth-closed oblique sagittal of right TMJ, the high signal fatty replacement in the superior belly of the LPM is observed more clearly (white arrow). The normal inferior belly shows isointense signals in either proton dense or T2-weighted image (compare image A and B). (C= condyle).

(C) Atrophy of the superior belly combined with contracture of the inferior belly of the LPM is noticed in the mouth-closed, oblique sagittal, proton dense image of left TMJ (3000/14, 1.5-T magnet). The size of the inferior belly of the left LPM is evidently enlarged comparing to the right side (comparing with image A). Fatty replacement and fibrosis are found in both bellies (small arrows). Anterior disc displacement can be observed (big arrow).

(D) T2-weighted (3000/125, 1.5-T magnet) mouth-closed oblique sagittal image of left TMJ, fatty replacement in both belly of the left LPM are evident (arrows).
Fig. 8 Contracture and atrophy of the LMP find in a 46-year-old female with a long history of chronic facial pain and movement pain on both sides and occasional locking of left TMJ. Anterior disc displacement with non-reduction is found in the left TMJ in MRI (C = condyle).
(A) Mouth-closed, oblique sagittal image of left TMJ (3000/14, 3-mm-thick), the atrophy of superior belly in the LPM shows as high-signal fatty replacement (white arrow). The contracture of the inferior belly shows fibrosis with lower signals (black arrow). The thickened disc is anteriorly displaced (white arrow head).
(B) T2-weighted image (3000/125, 3-mm-thick) of the TMJ in image A, the fatty replacement of the superior belly of the LPM (big white arrow) and the contracture of the inferior belly with lower signals fibrosis (black arrow) are more clearly observed. Effusion of the bilaminar zone (small white arrow) is suspected.
Fig. 9 Disc position of temporomandibular joint (TMJ) is demonstrated by MRI (C=condyle, E=articular eminence)

(A) Disc appears in normal position on mouth closed oblique sagittal PD (3000/14) (1.5-T magnet) MR image (arrow). The junction of bilaminar zone and posterior band of disc can be observed at 12 o’clock on the top of the condyle.

(B) In the same TMJ of (A), reduction of the disc (arrow) is seen in maximal mouth open direct sagittal T1-weighted (400/12) (1.5-T magnet) MR image.

(C) Anterior disc displacement (arrow) is seen in the mouth closed oblique sagittal PD (3000/15) (1.5-T magnet) MR image.

(D) Maximal mouth open direct sagittal T1-weighted (400/12) (1.5-T magnet) MR image of TMJ in Fig. C shows reduction of the disc (arrow). Fig. C and D presents anterior disc displacement with reduction (ADDr).

(E) Disc anterior displacement (arrow) with deformity is found in mouth-closed oblique sagittal (1.5-T magnet) MR image. Osteoarthritic change of the condyle can be noticed.

(F) In the same TMJ of Fig. E, maximal mouth open direct sagittal T1-weighted (400/12) (1.5-T magnet) MR image shows that the disc is still blocked in front of the condyle (arrow) and anterior disc displacement with non-reduction (ADDnr) is considered.
Fig. 10 Classifications of the condylar mobility: a horizontal tangential line of the top of the articular fossa and a vertical line through the top of articular eminence are made on sagittal or oblique sagittal image of TMJ. Two lines meet in point “O”. From the point “O”, making angles divide the articular eminence. The top of the articular fossa (TF) is on 0° and the top of the articular eminence (TE) on 90°. (C=condyle, E=articular eminence, TC=top of the condyle)

(A) Hypomobility (limitation) of the condyle shows in maximal mouth open imaging.

(B) Schematic representation of figure A, hypomobility of the condyle shows as the top of the condyle locates in 0°-90° (<90°).

(C) Normal mobility of the condyle shows in maximal mouth-open imaging.

(D) Schematic representation of figure C, normal motion shows as the top of the condyle located in 90°-120° of the eminence in maximal mouth opening.

(E) Hypermobility of the condyle is found. Note that the hypermobilized condyle may put pressure on the anterior part of the disc (arrow).

(F) Schematic representation of figure E, the condyle translates excessively, beyond and superior to the level of the articular eminence (>120°) in the images of mouth maximal opening.
Imaging abnormalities of the LPM can be found in TMJs with disc in normal position. The normal LPM may be observed in TMJs with severe osteoarthritic changes (C=condyle).

(A) Atrophy of the LPM superior belly in a 36-year-old female who has had progressing pain in the TMJ, facial and temporal pain on the right side for five years. Palpation pain in the LPM and movement pain in both TMJs. The mouth-closed oblique sagittal PD (3000/15) (1.5-T magnet) MRI image of the right TMJ reveals atrophy and fatty replacement in superior belly of the LPM (arrow). Disc appears in normal position. In maximal mouth-open images bilateral TMJ hypermobility is found.

(B) Normal image of the LPM is found in a 35-year-old male with painful locking, crepitating and movement pain in right TMJ, palpation pain of LPM and head-neck pain on both sides for three years. Pain symptoms have been released evidently after splint and psychical therapies, but mouth-opening limitation became worse. No palpation pain of the LPM and movement pain on both TMJs, slight palpated pain on right TMJ. The width of mouth opening is only 15mm. Mouth-closed oblique sagittal, PD image (3000/20, 3-mm-thick) of right TMJ shows severe erosion on the condyle (C). Disc becomes thinning (arrow). The LPM appears normal.