Chapter 1

Introductory Explanation of Masticatory Function

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1.1 Introduction

Mastication is one of the most important functions of the stomatognathic system. It is a highly coordinated neuromuscular operation and features rapid mandibular movements that demand continual modulation and adaptation to load. The nervous system, peripheral receptors (which determine sensory input), and the masticatory muscles (which produce the response from the brain and adaptation of movement) are continually involved during mastication. This is a complex process and plays a fundamental role in the quality of life for patients during childhood, maturity, and old age.

Mastication is a rhythmic and phylogenetically ancient movement. The best-known players in this process are the teeth; these are no longer a vital organ for humans (as they are for animals, for example), but they are still of fundamental importance both in terms of healthy functioning of the stomatognathic system and for social relationships. In fact, the peripheral input arriving from the periodontal receptors of teeth is numerically concentrated, sensitive, highly specialized, and extremely fast in reaching the neural centers allocated to masticatory control. Experimental studies on the topic have identified the mechanisms in animals during phylogenetic development that maintain and control the chewing cycles, mechanisms that are extremely precise in humans too. However, it is the cerebral cortex – which is so developed in human beings that it takes up half of the brain area – that controls the chewing pattern.

At this point, the “clinical physiopathology of masticatory function” becomes of specific interest, particularly the search to link masticatory function with dental occlusion, structural and neuromuscular structures, and the whole brain (Figure 1.1). This scientific interest emerged and was developed during the 1980s at the School of Orthognathic Studies in the University of Turin under...
the leadership of Professor P. Bracco. From the very outset, he focused on a functional, multidisciplinary, and especially gnathological approach to the diagnosis and therapy of malocclusions. The study and comprehension of masticatory function was supported by this underlying methodology, without which the research carried out would have been limited to the simple publication of statistical results without any true contribution being made to the improvement of diagnostic and therapeutic procedures. Such contribution is, however, the true objective of all research.

In the fields of orthognathics and prosthetics, the study of occlusion is extremely important, particularly as the correlation between “occlusion” (involving the teeth of upper and lower dental arches), function, aesthetics, and social relationships becomes increasingly acknowledged. An understanding of the relationships between dental occlusion and neural control has been improved beyond question by gnathological knowledge of occlusion (Figure 1.2). It was also clear from very early on that, in order to understand and establish a meaningful clinical study, the gnathological base would have to be supported by an understanding of neurology. The concepts of functional occlusion and neuromuscular control are very close to the question of medical treatment of the psychophysical aspect of humans. This concept is clearly expressed in Springer’s *International Journal of Stomatology and Occlusion Medicine*, a title created by

![Figure 1.2](image)

**Figure 1.2** The stomatognathic system: relationships between dental occlusion, temporomandibular joint (TMJ) and neuromuscular control. *Source for the muscles*: redrawn from Neff (1999). *Source for the brain*: Purves et al. (2000). Reproduced with the permission of Sinauer Associates.
Professor R. Slavicek, one of the most important and dedicated modern-day gnathologists. Dentistry deals with one of the most refined anatomical areas of the body from a neuromuscular point of view – it has an incredible ability to adapt, which, instead of being abused, should be studied and understood in all its physiological aspects in order to allow treatments, “cures” even, that improve its functioning and, consequently, the general psychophysical health of the patient. We hope, then, that the study of mastication can help achieve this objective.

The information gathered from chewing patterns is important in diagnosing the functional condition of the patient; for example, the repetition and variability of mandibular movement, neuromuscular coordination between the two sides, or the ability to adapt to load while chewing a hard bolus. As the brain is entirely engaged during chewing, the importance of this study from a clinical point of view is clear, but the technical, statistical–mathematical, and numeric difficulties have meant that only professionals working specifically in this field have been involved in the research so far. One aspect of evolution is to simplify complex processes, and this is the aim of this book, a first step in this direction. The fine-tuning of functional magnetic resonance imaging (fMRI) has allowed the study of neural control in humans, which we hope will permit us to better understand the functioning of the central nervous system.

The study of masticatory function began at the University of Turin in the 1980s, when the first devices for recording human chewing patterns were produced and sold. The necessary hardware and software were developed and fine-tuned over many years, thanks to the fundamental and collaborative work of the bioengineers Professor D. Farina and Dr A. Merlo. We will later look at the intrinsic difficulties encountered in the study of functional movement from a statistical–mathematical point of view, which were overcome thanks to the skill and effort of these professionals – without their contribution, none of the results later achieved would have been possible. Not only the bioengineers, but also many researchers, professionals, students, and volunteers dedicated their time and energy to this research, even during the period when its clinical significance was still unclear. We believe it important to underline this contribution to clinical research, which requires a true and homogeneous team who all offer hard work and intellectual integrity, albeit in different capacities. These elements, along with a smidgeon of good luck (or, rather, the open-minded approach necessary to identify an important finding amongst millions of others) are essential in achieving scientifically valid and sound results. True research (which presupposes the objective of increasing and developing knowledge) requires skill and passion, as opposed to personal interests connected to obscure indexes of scientific impact. Using research results that have clarified the correlation between masticatory function and occlusion as a starting point, two new directions have emerged thanks to a collaborative partnership between Professor G. Anastasi (University of Messina Italy) and Professor P. Bramanti (IRCCS Centro Neurolesi “Bonino Pulejo,” Messina, Italy) – the study in fMRI of neural control during chewing and the histological and biomolecular study of the sarcoglycan–integrin system of the masseter muscle:

1. **The use of fMRI has allowed the study of neural control in human chewing** (Figure 1.3) and represents a step forward in the correlated research not only in dentistry but also, and principally, at a neurological level because it has permitted us to widen our knowledge about the central nervous system via the study of a complex automatism i.e., mastication. Both neural control of mastication and the phenomenon of occlusion differ greatly in their characteristics with regard to human beings as opposed to most species of animals (particularly small laboratory animals). Thus, the study of mastication is now moving beyond the confines of dentistry, the area in which it started, to develop within the field of human neurology and contribute, hopefully, to the understanding of much more serious and debilitating conditions than malocclusion.

2. **The morphological and biomolecular aspects of masticatory muscles are currently a focus of interest.** Despite the fact that considerable information exists, various questions still remain
about these muscles that are characterized by special features, both macroscopic and microscopic. However, if the characteristics of a complex muscle like the masseter are to be understood well, it is necessary that there be a strict correlation with the clinical features of masticatory function.

We have outlined these innovative aspects of the study of masticatory function in order to introduce the reader to the topic with an open mind, putting aside preconceptions and convictions that in no way aid true and in-depth understanding of the overall subject.

We wish to underline above all the fact that the stomatognathic system’s capacity for “functional compensation” cannot be used as an excuse to justify all and any type of therapy. It is true that the stomatognathic system possesses remarkable (although restricted) compensatory capacities, but it is also the case that, in general, it has no autocorrection capacity. This means that, during life, the compensations made will add up and overlap, also with those of poorly selected therapies, to the point where the system is unbalanced and then recovery becomes extremely difficult due to the need for multifactor and multidisciplinary solutions.

The only way to avoid such an imbalance is to prevent it – this is why we must try, using the appropriate treatment, to restore ideal physiological conditions in each patient (Figure 1.4). A working knowledge of ideal functioning conditions for each human is important if the right therapeutic cure is to be selected, without adverse side effects that may at times remain hidden, undiagnosed,

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**Figure 1.3** Functional magnetic resonance has allowed the study of neural control during masticatory function. *Source: Bracco et al. (2010). Reproduced with the permission of Maney Publishing.*
Understanding Masticatory Function in Unilateral Crossbites

Diagnosis and a correct physiological therapy are made. But once a phase of compensation is initiated, due to the malocclusion per se or to a traumatic and non physiological therapy the situation is much more difficult, as it becomes multifactor and multidisciplinary, and no feasible solution may remain. Thus, we have to make every effort possible to avoid this phase of imbalance by intervening promptly to correct the occlusal and functional disease with treatments appropriate to physiological and biological conditions. In fact, compensation is evoked to preserve fully functioning order in the best way possible, but at times this may produce collateral damage in the long term. Many discussions, opinions, and arguments have been forwarded on this question, but it is the physiological aspect, not the philosophy of the issue, that interests us. And the physiology can only be studied, understood, known, and respected.

The topic is extremely complex and, unfortunately, we do not yet have the right diagnostic means available to fully understand the limits of the stomatognathic system’s compensatory function. Therein lies the real aim of this book: to provide the reader with simple means for a general comprehension (supported by reliable scientific results) of mastication, in order to enable him/her to choose respectful therapies and treatments. We hope that the book will help professionals in various sectors (including orthodontists, dentists, neurologists, psychiatrists, pediatricians, rehabilitation physicians, physiotherapists, osteopaths, and sports coaches) to understand the causes, development, and consequences of malocclusion in childhood and maturity, in order to adopt and refine therapies that take both physiology and biology into consideration. To achieve this aim from a practical and not simply theoretic point of view, and to learn how to “think physiologically,” we need to put aside all our preconceptions and old ways of thinking to make a slight initial effort to study this new subject. Orthognathodontics, just like any other profession, is in continual evolution, and it is currently of clinical relevance in successful orthodontic or prosthetic treatments to consider not only the repositioning or substitution of teeth within the dental arches, but also, and above all, the effects of treatment on the functional working of the masticatory system.

1.2 The study of masticatory function

It is now time to describe briefly the intrinsic difficulties in the study of mastication, from both technological and clinical points of view, in order to show the reader the evolution, benefits, and limits of the research. Mastication is a complex rhythmic movement that has been refined over millions of years in the animal world and is characterized by precise and reliable neuromuscular
control. Thus, the study of this function is extremely complex and requires not only advanced technological tools, but also clinical experience and skill. Furthermore, intellectual integrity is vital, which is why we have published these results only after confirmation at least twice by different groups of researchers treating different patients. Clinical experience, then, is the basis of research planning in order to have a logical plan of action with its roots in physiology – when the research plan is not underpinned by knowledge and experience, there is a danger of producing untrustworthy results. One of the most common defects in the literature is in regard to the nonhomogeneous nature or inaccurate selection of samples where homogeneity is a vital factor. Technological evolution and compliance have also played an important ongoing role.

As a result of the discrepancy between technological resources and clinical comprehension, there was an initial period of confusion that was only resolved with many years of research and effort to gain reliable data. In the 1980s, computers were certainly not so advanced as nowadays, but they could still supply long lists of numbers tracking the movement of the mandible in the three planes. In this initial painstaking phase, all effort was focused on discovering how and in what length of time data could be collected, on the alignment and successive processing of data from different sources, and on the instructions to technicians involved in data collection so that they could record cases reliably. In other words, this period concentrated on resolving solely technical issues, in order to tackle the true question of which and how many of these machine-generated numbers could be used in clinical research. Perfecting the pathognomonic framework was a lengthy and arduous process, closely linked to the technological evolution of hardware and software. In particular, the relevant software was totally rewritten and adapted to the current clinical and technological progress. This took place following an in-depth study alongside bioengineers because it was clear from the start that the study of masticatory function was badly served by the laws of mathematics and statistics. In fact, as chewing patterns are characterized (in physiological conditions) by a balance of repetition and variability, it is difficult to link this study to the mathematical–statistic laws that the international scientific community holds dear. For this reason, much attention was paid to refining a software program that is suitable for the processing of collected data.

The software currently being used in research allows a reliable reading of basic data of chewing patterns and muscular activity, which will be described in Chapters 2 and 3. However, it is necessary to point out that masticatory function cannot be compared with a hemochemical test – to be correctly analyzed, it needs to be linked to clinical, occlusal, cranial, articular, muscular, and, in some cases, emotive characteristics of the patient, as previously mentioned. The dentistry profession is obviously interested in the relationships between occlusion (or malocclusion) and chewing patterns. However, as humans are psychophysical beings, the emotive aspect can in some cases become a significant factor, influencing not only the pattern but also the entire motor control of the jaw movement. Thus, it is clear that a multidisciplinary approach to this study is essential, with expertise from various fields being integrated for maximum efficiency.

We will now dedicate a few lines to some key authors in the field who have influenced the work described in this book. Possibly for the reasons outlined above, the research and study of mastication have been awarded little attention, generally by just a handful of international authors. First, we will give a brief description of the significance of early research studies into the topic, looking more closely at those which influenced current understanding of chewing patterns.


E. Moller 1960–1970: he carried out an electromyographic (EMG) study of the masseter and temporal muscles of mastication during chewing in order to identify the characteristics of masticatory muscle coordination, a vital factor in understanding neuromuscular control of chewing kinetics (Moller, 1966).
These two authors carried out their studies without the possibility of analyzing mandibular kinetic movement and EMG activity simultaneously. However, despite the limited technology of their age, their results demonstrate high levels of awareness of the issues involved and clinical experience.


C. H. Gibbs and A. Lundeen 1980–1990: these scholars studied chewing patterns using the “case gnathic replicator,” an unwieldy device that was difficult to use and required considerable effort but which allowed the collection of data that are still considered accurate and valid today. Moreover, the device succeeded in registering masticatory movement at interincisive, bilateral molar, and bilateral articular levels. These authors described chewing cycles with mathematic precision, making an important contribution to the understanding of masticatory function. Their vital research results are described in Chapter 2 (Lundeen and Gibbs, 1982).

A. Lewin 1985: Lewin focused on the study of mastication in the same period as Gibbs (1989–1990), laying the foundations for diagnostic analysis today. He studied chewing patterns with the “Sirognathograph,” a less invasive tool than the case gnathic replicator that also proved easier to use. Thanks to his experience and intuition, Lewin was able to identify the clinical features of chewing patterns, which were then confirmed by further studies and are outlined in Chapter 2 (Lewin, 1985). He is a cornerstone in the field.

J. P. Lund 1970–1990: carried out basic research on the topic and was the first to prove the existence of the central pattern generator (masticatory-like rhythmic bursting in NVsnpr neurons) in the brainstem. This was a vital step in understanding neural control of mastication (Delloy and Lund, 1971; Bernier et al., 2010).


The key research authors that this book makes reference to are C. H. Gibbs and A. Lewin, who conducted their research studies with very different tools from both conceptual and practical points of view (case gnathic replicator and Sirognathograph). They were also very distant geographically, coming from the USA and South Africa, but were active during the same time period (1980–1990). Current research on chewing cycles still today refers to these authors’ results and concepts, reconfirming their validity.

### 1.2.1 The case gnathic replicator

The American researcher Gibbs (1985, USA) developed the first machine designed not only to record human mandibular movement but also to reproduce said movement later. The process involved a heavy, unwieldy, and invasive device, but it had a huge advantage over previous methods in that it allowed the recording and (even more importantly) the reproduction of chewing patterns in plaster models of the dental arches, controlled by six small servomotors for precise and reliable results (Figure 1.5).
Following their research study, Gibbs and Lundeen were able to produce literature on *chewing cycles at the inter-incisive level and at the molars on the right and left, as well as on bilateral temporomandibular movement*. Their work clarified the process of condylar movement during mastication. At that time, the use of axiographic tracing of TMJ movement was common (opening, closing, protrusion right and left-hand mediotrusion). Great astonishment greeted the discovery that, during mastication, the opening and closing patterns of the condyle on the bolus-loaded side are different to those of the contralateral. This, in fact, meant that at no point in mastication or in any masticatory movement was the position of the condylar axis the point of reference, as it was for all gnathology and dentistry study.

Given the complexity of the device involved, Gibbs’s study was carried out on a limited number of patients and, despite the author’s intentions, he never managed to make the device feasible for larger-scale studies. However, as already stated, the results obtained are important and still considered valid today (Lundeen and Gibbs, 1982).

### 1.2.2 The Sirognathograph

At the same time that Gibbs was developing the case gnathic replicator, Lewin (1985, South Africa) was perfecting his Sirognathograph, produced by Siemens (Germany). This was a much simpler piece of equipment to use, but, as a result, was able to produce less data than Gibbs’s case gnathic replicator. Lewin’s device records the *movement from one point of the mandible*, using a small magnet attached labially between the lower central incisors. The advantage of this method lies in the fact that it is less invasive, both regarding the stomatognathic system in general and the occlusion itself. The weight of the Sirognathograph antenna frame on the head and neck was an initial problem (Figure 1.6) but this problem was later resolved with increasingly advanced technology. It is also easier to use, allowing more cases to be studied (an important factor in developing clinical analysis of chewing patterns). The contribution that Lewin made to clinical analysis and clarity of
ideas on the protocol for recording chewing function remains fundamental in the research field even today, as his ideas and intuition are continually reconfirmed with more refined tools (Lewin, 1985). The research reported in this book is based on his teaching and guidelines.

1.3 The evolution of electrognathography and electromyography

While case histories, objective clinical examinations, experience, and diagnostic skill of doctors and dentists are essential elements in both professions, the use of advanced technological equipment permits the collection of clinical data that would not otherwise be possible. In particular, for mastication, although it is initially difficult to acquire this data and even more difficult to analyze it, great effort has been put into the development of hardware and software even when many researchers still openly criticized the use of diagnostic tools, claiming that clinical tests were more than sufficient for a correct diagnosis. We now know this is not true – whilst in no way diminishing the importance of clinical tests, the very fact of knowing the characteristics and correct or incorrect functioning of mastication, as well as being able to check post-treatment alteration, is important in the choice of corrective treatment from anatomic and mechanistic points of view and for the restoration of masticatory function in both evolutionary and growth phases. Here, we will outline the evolution of electrognathography to explain how the recording of such a process, whilst seeming relatively simple, in fact required a lengthy and careful process to develop a valid and reliable tool that is also practical and easy to use. This objective was reached along with the clinical analysis of results that, for some types of malocclusion, is today finally clear and scientifically demonstrated.

1.3.1 Plotted masticatory cycles

This book is based on research results that were initially gathered with the use of the Sirognathograph, developed by A. Lewin and produced and sold in the 1980s by the German company Siemens (Figures 1.7 and 1.8). This device recorded the movements of a magnet which was inserted labially in the lower midpoint of central incisors, and used an antenna frame with multiple sensors to track the motion of the magnet. At first, the Sirognathograph was not connected to a computer or EMG equipment. Connected to a plotter, it reproduced the mandibular movement of single chewing cycles in the three planes (frontal, sagittal, and transverse), but it

Figure 1.7 Magnet of the Sirognathograph.
was impossible to process or archive any of the collected data (Figures 1.9 and 1.10). Plotting took around 30 min and demanded the constant presence of a technician to change the sheets. Furthermore, it was not possible to gain any information on masticatory muscle activity as the gathering of kinematic and EMG data was still problematic from a technological point of view; thus, in that period, the two processes (study of muscle activity and kinematic recording of mandibular movement) were carried out independently of one another. The need for computerized
analysis of the complex masticatory function was soon obvious, and thanks to technological progress the Sirognathograph was soon linked up to an IBM computer.

1.3.2 1983: Early computer processing of plotted data on chewing cycles

The use of electrognathographic equipment for medical purposes allows the collection of large amounts of numeric data, but it also poses the problem of the difficulty of clinical analysis of said data. However, the need to process and record the numeric data on chewing cycles led to the connection of the Sirognathograph to a computer in 1986 (Figures 1.11, 1.12). The aim was to obtain the average chewing pattern, with the printing of charts and recorded data storage (Bracco et al., 1990). The development of statistical and mathematical formulae to identify the average cycle (typical of the real chewing pattern in patients) required great effort and close collaboration with a valuable bioengineer E. Fabris. The difficulty of statistical–mathematical analysis of chewing cycles lies in the variability of the patterns, which is an intrinsic and fundamental feature in physiological conditions. However,
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Another equally important characteristic is the repetition of patterns, which is easily identified by customized software. It was necessary to rewrite the program a number of times to apply the correct statistical–mathematical laws most appropriate to the intrinsic variability and repetition of masticatory patterns.

The first version of the program produced a graph of the average cycle on the frontal, sagittal, and transversal planes and the average duration time, allowing computerized data storage or printouts of data with significant savings of time and money. Also, thanks to computerization, it was possible to introduce the use of colors to distinguish patterns by using blue to represent opening and red for closing – this was a huge step forward in the understanding of masticatory patterns from a diagnostic point of view. The computer program was extremely advanced in comparison with our ability to interpret the results.

1.3.3 1986: First recording of chewing cycles in alignment with electromyography of the masseter and anterior temporalis muscles – customization of software

One important innovation for the reading and understanding of chewing cycles was surely the recording of EMG activity of the four masticatory muscles aligned to mandibular kinetic motion (Figures 1.8 and 1.15).

Only four of the eight masticatory muscles can be recorded with surface electrodes (right and left masseters, and right and left anterior temporalis). The other four (medial and lateral pterygoids) are detectable only by needle EMG recording, which is not suitable for the purposes of studying mastication. However, the different role of the masseters compared with the anterior temporalis muscles allows us to collect significant data that can help us understand the neuromuscular control of masticatory function. To this end, it is necessary to clarify that the clinical importance of muscular activity during mastication is not so much connected to absolute EMG values, which are extremely sensitive to individual variables, as to the evaluation of muscle...
Figure 1.13  First plots of mandibular kinetic movement in frontal, sagittal, and horizontal planes (top) aligned with electromyography envelope plotted versus the vertical jaw displacement, of right and left anterior temporalis muscles and right and left masseters (bottom). Red tracings: opening; blue tracings: closing.
Figure 1.14 First printing of plots of average chewing pattern and velocity versus the vertical jaw displacement. Red tracings: opening; blue tracing: closing.
coordination on the two sides. It is true that the reliability of EMG evaluation of these muscles has been confirmed (if carried out correctly), but it is necessary to look at coordination between the muscles during the study of masticatory function.

From a technical point of view, this evolution called for extremely advanced technological and resources considering the time in which it took place (Bracco et al., 1999). The EMG recording of muscular activity aligned with mandibular kinetic movement represented an important step forward in clinical comprehension and diagnostic analysis of mastication in both physiological and pathological conditions (Figures 1.13, 1.14, and 1.15).

In order to be completely reliable, the study of muscular activity during mastication requires a huge amount of data. Individual variables in EMG activity is an intrinsic feature of mastication, whilst muscle coordination is an objective point of reference. The statistical evaluation of patients with accurately identified malocclusions (from a functional viewpoint) allows the identification of pathognomonic EMG features. Understanding neuromuscular activity and coordination between the muscles on the side of the bolus and contralateral muscle during mastication of hard and soft boluses is of fundamental clinical importance for the correct treatment of both youngsters and adults.

1.3.4 1992: Replacement of the Sirognathograph with a customized K6-I kinesiograph instrument – rewriting of the software

A further technological innovation took place when the Sirognathograph was replaced with the K6-I Myotronics kinesiograph (Tukwila, WA, USA). This move was imposed by circumstance rather than by choice (as opposed to the actively sought selection of EMG), due to the decision of Siemens in the 1990s to stop producing the Sirognathograph. Owing
to its similar features, the K6-I Myotronics kinesiograph was chosen as a substitute (Figures 1.16 and 1.17).

The K6-I system was based on the same principles for recording mandibular movement and also offered the possibility of recording muscle activity of the four, aligned, masticatory muscles. The improvement resided in the more precise recording of movement and, above all, in the reduced invasiveness of the device thanks to its lighter weight and more anatomically friendly shape of the recording structure. However, from a software point of view, it was now practically back to square one!

The K6-I required the insertion of powerful hardware boards into a PC. The system unit had to be laid horizontally to prevent the large K6 boards touching other parts of the computer and damaging them. Both the antenna and the preamplifier were connected to the desktop PC and the equipment could not be moved in any way. The K6-I software was not originally developed for chewing cycle analysis, and so it was necessary to adapt the system with personalized software as well as writing new software for processing. It was the period of IT experts and it resulted in a transition software (Figures 1.16 and 1.18).

Figure 1.16  Multiple-sensor lightweight array of the kinesiograph (Myotronics, Tukwila, WA, USA).

Figure 1.17  K6-I kinesiograph (Myotronics, Tukwila, WA, USA).
Figure 1.18  Prints of mandibular kinetic movement in frontal and sagittal planes (top) aligned with electromyography recordings of right and left anterior temporalis muscles and right and left masseters (bottom) after one of the rewriting of the software. Green tracings: opening; red tracings: closing R right, L left.
1.3.5 2002: From K6-I to a customized and portable K7-I – the software is rewritten again

The K7-I is the latest and most evolved model in use today, particularly regarding hardware and EMG recording. It can be connected to a laptop via USB, and the K7-I itself can be moved (Figures 1.19, 1.22, and 1.23). The software for analyzing chewing cycles was yet again rewritten for the third time in accordance with the improved understanding of the clinical significance of chewing patterns acquired in the meantime.

Certainly, as time passed, and hundreds of chewing cycles from patients were rigorously classified, grouped, and recorded, we were able to identify from this mass of computer data the most significant figures from a clinical point of view. The last-generation program represents an important step forward, particularly in calculating the mean cycle and in EMG recording. Furthermore, the coordinates of points and angles of clinical significance are automatically provided in diagnostic charts to make it easier to interpret graphs and statistical analysis of results. The mean cycle and EMG activity are presented in linear graph form, whilst standard deviation is represented by an area chart. In the first program, standard deviation was displayed with horizontal lines, whilst in the new program an area chart is used to give a more realistic idea of the movement. This innovation is important, in that the standard deviation represents pattern variability, which is a physiological feature. The shape and position of the area represents diagnostic data which can be visually memorized more quickly and easy than lines (Piancino *et al.*, 2008) (Figures 1.20 and 1.21).

The instrument and program described (and currently in use) are for research purposes. Thanks to the results collected, a simple and quick system, utilizing wearable inertial units, is currently being developed to allow doctors to gather useful functional data for everyday use in their work.

![K7-I kinesiograph (Myotronics, Tukwila, WA, USA).](image)
Figure 1.20  Print of chewing patterns in frontal, sagittal, and horizontal planes of the program dedicated to the K7-I kinesiograph; the solid line (green for the opening pattern and red for the closing pattern) represents the average chewing cycle of three trials lasting 10 s each. The green and red shaded areas represent the standard deviation from the average cycle.
Figure 1.21  Print of an average chewing pattern in the frontal and sagittal planes (top); electromyography envelope plotted versus the vertical jaw displacement. The solid line (green for the opening pattern and red for the closing pattern) represents the average chewing cycle of three trials lasting 10 s each. The green and red shaded areas represent the standard deviation from the average cycle.
**Figure 1.22** Multiple-sensor lightweight array of K7-I kinesiograph (Myotronics, Tukwila, WA, USA).

**Figure 1.23** Magnet of the K7-I kinesiograph (Myotronics, Tukwila, WA, USA).
1.4 From the 1980s to today

1.4.1 The bolus

One of the most important aspects in a reliable study of masticatory function is surely the choice and standardization of the bolus. In fact, as stated in the literature (Lewin, 1985; Plesh et al., 1986; Bishop et al., 1990; Shiau, 1999; Miyawaki et al., 2000, 2001; Lassauzay et al., 2000, Shiga et al., 2001; Anderson et al., 2002; Piancino et al., 2008), the morphology of the pattern is directly linked to the chemical–physical characteristics of the bolus and its size. Random or varying choices of bolus types added to nonhomogeneous protocols, and sample selections means that masticatory research detailed in the literature is difficult to compare and standardize, and may even be unreliable at times.

The initial stages of research were carried out using simple chewing gum. From A. Lewin’s work, it was clear that the use of both soft and hard bolus types in diagnosis was important to compare the patterns achieved and the capacity of the stomatognathic system to adapt to load (i.e., the differing bolus consistency). Thus, much attention was paid to the choice and standardization of bolus types; and from the very beginning, in the mid-1980s, patients with their own teeth were tested with two standardized boluses in terms of weight and dimension, according to parameters still adopted today: a soft bolus and a hard bolus. The soft bolus is a chewing gum, first softened up by the patient. The chewing cycles achieved with this bolus represent an “ideal” mastication as it does not change in consistency or volume and offers only limited resistance, thus submitting the system to low load. The hard bolus, on the other hand, is a winegum that does not stick to the teeth, changes consistency and volume as it is chewed, and demonstrates the true masticatory capacity. Many tests were carried out to identify the best type of bolus to use in order to allow a comparison of exertion: both boluses were the same size (20 mm in length, 1.2 mm in height, and 0.5 mm in width) but of different weights (2 g for the soft bolus and 3 g for the hard bolus) and different consistency (puncture forces 0.36 N for the soft bolus and 1.85 N for the hard bolus). But it is the comparison of patterns achieved with two boluses (as opposed to an absolute evaluation of one bolus or another) that allows the diagnosis of “capacity to adapt to load,” as Lewin defined it.

The standardization of bolus types (like the standardization of the protocol, the position of the patient, etc.) is essential in achieving reliable and repeatable tests. We would like to make it clear that, in order to be of diagnostic importance, the recording of mastication must have a “test of exertion” as opposed to just a spontaneous instinctive movement that is subject to unacceptable variables for any type of scientific research. In any case, knowing that mastication is influenced by the limbic system also, it is important to know and respect the patients’ taste in order to choose the most suitable flavor of the bolus (e.g., spearmint or strawberry chewing gum). If a spearmint chewing gum is given to a patient who hates this taste, the chewing pattern recorded will be pathologically false and of no clinical significance.

The types of bolus described are suitable to the recording of chewing cycles in patients with their own teeth – they cannot be used for toothless individuals or with tools that require different duration of sets of chewing, which instead require specific bolus types expressly made.

1.4.2 The protocol

The instrument used in this type of research is a kinesiograph, which involves the insertion of a small magnet to the labial surfaces of the mandibular incisors alongside a headframe that consists of an antenna system (to record the changes of the magnetic field) in the manner of an eyeglass. The kinesiograph also records the aligned EMG activity of four masticatory muscles: the right and left temporalis muscles, and the right and left masseters. Earlier, we
described the complex but essential progression from single kinematic recordings to the simultaneous acquisition of jaw movement and EMG activity. The choice of the kinesiograph tool was not accidental, as may initially appear, but was the result of long deliberation by bioengineers. The alternative was an optoelectronic device. The kinesiograph was chosen instead because it was easier to use and provided more reliable results, important factors in large-scale clinical testing where a lot of data are lost during the process.

The protocol for recording chewing cycles, like the choice of bolus, was refined in collaboration with Lewin after long and careful experimentation. Indeed, the protocol and bolus choices remain the same to this day and produce diagnostic data that is both suitable and necessary for a complete diagnosis both of mandibular movement and of the related neuromuscular activity. The key factors are:

1. The position of the patient during the test. This is vital in achieving reliable and repeatable results. Thus, the position of the patient must not be casual but needs to be standardized – seated upright, legs at 90° and eyes fixed on a point 1 m away. This position is designed to reduce indirect movement to a minimum, (i.e. those movements related to mastication, particularly of the neck), in order to record mandibular movement connected to bolus chewing as precisely as possible. We know from the literature that the neck muscles and masticatory muscles mutually coordinate, and that holding the head steady allows indirect movement of the mandible to be prevented (Eriksson et al., 1998).

2. The test protocol. The test involves deliberate mastication on the right side and on the left side, and free mastication. Each masticatory set is repeated three times, first with a soft bolus and then with a hard one. In total, nine sets with soft bolus and nine sets with hard bolus are recorded. Each set lasts 10 s, the mean time of mastication before swallowing occurs (Piancino et al., 2008) (Figure 1.24).

3. The recording of EMG activity. As already mentioned, the recording of muscle activation requires the acquisition via surface electrodes of four of the eight masticatory muscles (i.e. the frontal temporalis muscles and the masseters). For anatomical reasons, the remaining four muscles (inner and outer medial and lateral pterygoids) are not compatible with the use of surface electrodes. However, if used correctly, the frontal temporalis and masseter muscles supply more than sufficient data for the purposes of understanding a patient’s chewing conditions. Although modern technology would certainly allow it, it was decided not to expand the collection of data via surface electrodes to other muscles (such as the opening muscles or those of the neck) because, considering the clinical and statistical complexity of the masticatory system, it was preferred to concentrate on those masticatory muscles most directly involved in chewing. Over time, this was proven to be a wise decision, and currently it would be simple, if necessary, to expand EMG readings.

We wind up this topic by underlining that mastication is a complex function, the study of which requires considerable clinical experience, combined with appropriate instruments and protocols. Only in this way can reliable and clinically significant data be gathered.

### 1.5 Ready to start

Having described the clinical objectives, technological difficulties, and evolution of the research, as well as outlining the general characteristics of mastication and the study of this process, we are now ready to explore the topic more in depth. Chapters 2 and 3 are dedicated to the physiology of mastication, which is an essential factor in understanding the functional anomalies connected to malocclusion, or conditions of pain and dysfunction, and so on. As stated in the title, this book is dedicated to one type of malocclusion in particular: *the unilateral crossbite,*
the form most responsible for altering physiological mastication (Figures 1.25 and 1.26). This condition is more serious the earlier it occurs, worsening over time, and irreversible once skeletal maturity has been reached. The task was to refine a therapeutic treatment suitable for the correction and prevention of such a disabling condition of the stomatognathic system. At the same time, an effort was made to understand the changes to masticatory function that are directly linked to unilateral crossbite, and to check that the treatment not only corrected the

Figure 1.24  Print of the superimposed chewing cycles in the frontal plane: deliberate right-hand and left-hand mastication (top); free (alternate) mastication (bottom). Green tracings: opening; red tracings: closing.
malocclusion but also restored the functional capacity. This book will cover this issue, hopefully in a manner as clear and unquestionable as the results of tests in this field themselves. Many other results linked to other types of malocclusion, neurological conditions, orthopedic conditions, prosthetic rehabilitation, and so on we have also been gathered, verified, and published, but, given the complexity and current scarcity of literature on this topic, we have chosen to limit the extent of this book as an introductory work in order to allow the reader to focus on, and understand more easily, the results of this study.

References


Figure 1.25  Left unilateral posterior crossbite before correction in mixed dentition.

Figure 1.26  Dental occlusion after functional correction.


