Electronic Auscultation and Sonagraphic Audio-Spectral Analysis of the Temporomandibular Joint

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ELECTRONIC AUSCULTATION
AND
SONAGRAPHIC AUDIO-SPECTRAL ANALYSIS
OF
THE TEMPOROMANDIBULAR JOINT

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INTRODUCTION

In these current scientific oriented decades, the various disciplines of dentistry have become cognizant of the multitude of diverse concepts, principles, and methods of diagnostic evaluation and treatment of dysfunctional relations of the stomatognathic apparatus. Unfortunately many distinguished contributors in the field of occlusion and temporomandibular joint function have strong, inductive, empirical convictions that divide the dental profession into diametrically opposed academic camps, proudly displaying their singular panacean solutions to a veritable kaleidoscope of problems. Students develop tolerance of differences in opinion, but experience difficulty in the categorization of divergent literature. An enormous amount of literature dealing with functional relations of the stomatognathic apparatus is controversial. This controversial aspect is apparent when viewed from different vantage points. Prosthodontic, orthodontic, periodontic, and gnathologic disciplines have their self perpetuating concepts, but all hopefully possess a common goal....

"Academic Progress." Disunity in schools of thought and
fragmentation of the disciplines merely identifies an intellectual hiatus which must be researched.

It is the object of this investigation to measurably narrow subjectivity of analysis of TMJ sounds. An attempt to analyze sounds elicited by the temporomandibular articulation upon functional mandibular movement has been performed. A quantitative and qualitative assessment of TMJ sound was completed by utilization of an audio-frequency spectrum analyzer (Sonagraph 7029A, Kay Elemetrics Corporation, Pine Brook, New Jersey). This instrument records sound waves in the form of a paper tracing. The Sonagraph is capable of a spectral analysis of a complex signal, breaking down the signal into each frequency component and recording amplitude and level in decibels of each component as a function of time.

The diagnostic significance of TMJ sounds has been traditionally a controversial subject. The mere fact that joint sounds are present and vary in description from one author's interpretation to the next, in itself, warrants close investigation.

Throughout the literature, mention of clicking and crepitation as related to TMJ dysfunction and pathologic
occlusion has long been postulated to be significant. From the empirical analogy of a car mechanic electronically recording the sounds elicited by an automobile engine to the pragmatic analogy of the cardiologist basing his diagnosis and treatment of cardiac afflictions on heart sounds; it is well accepted that a well tuned engine has normal sounds to the car mechanic, a healthy well functioning heart has normal sounds, and an asymptomatic, proper functioning temporomandibular articulation should elicit normal sounds. Whether TMJ sounds are normal for the individual based upon the populus norm can be determined only if a hypothesis is advanced, based upon research, that crepitus can assist diagnosis by eliminating degrees of empiricism.

A review of past and present methodology of clinical and laboratory investigations of the temporomandibular joint was carried out placing major emphasis on the subject of TMJ crepitation and clicking. Related subjects that are included in the review of the literature are: Morphologic, Anatomic and Histologic considerations; Classification and Interpretation of normal and abnormal TMJ function; Contrast roentgenographic, laminographic, and cineflurographic
investigations; Physiological and electromyographic studies; Masticatory force distribution patterns; Effects of anterior or posterior mandibular displacement; Cardinal symptomology of TMJ pathosis; Effect of pathologic or destructive occlusal forces; Psychosomatic and neurological considerations; Previous stethoscopic and electronic auscultatory techniques; and, a brief review of some pharmacologic and therapeutic methodology.
CREPITATION AS RELATED TO T.M.J. DYSFUNCTION:

In reviewing the related literature it was found that a multitude of material has been written on the subject of myofacial neuralgia and temporomandibular joint dysfunction. Most authors refer to temporomandibular joint clicking, snapping, popping, or crepitus as part of the myofacial pain syndrome. (Costen, 1934 Syndrome, TMJ arthrosis, etc.) Joint sounds have been described subjectively from a clinical standpoint as being either present or absent. Only two or three studies have made an attempt to describe temporomandibular joint sounds objectively. Presently there is no evidence of an objective clinical norm for temporomandibular joint sounds.

EARLY STUDIES:

Axhausen (1930) was one of the first to observe that more than one click can occur at various stages of sagittal openings of the mandible. He noted two types of clicks and called them the "intermediate click" and the "final click". Pringle (1918) felt that clicking was caused by
dislocation of the meniscus. He associated the pain of temporomandibular joint arthrosis with an audible snap or click.

CONTRAST RADIOGRAPHY:

Norgaard (1947) utilized a unique TMJ roentgenographic technique using a special contrast medium injected into the joints. He stated: "Apart from cases of traumatic injury, the patients who most often apply for x-ray examination of the temporomandibular joint complain of cracking of the joint and other symptoms of temporomandibular arthrosis—e.g., diminishing of the mobility and pain on movements.". Norgaard called his roentgenographic technique Temporomandibular Arthrography and the resulting roentgenograms were called arthrograms. In the same year (1947), Bowman correlated TMJ clicking to pathologic occlusion which was further supported by others in the future.

T.M.J. ARTHROSIS SYMPTOMOLOGY:

Foged (1940) suggested the name "arthrosis temporomandibularis" for the previously mentioned group of symptoms. The first description of TMJ Dysfunction was by Cooper (1823), and in 1887 Annodale wrote of the first surgical procedure
for fixation of the meniscus. His treatment of the disorder consisted of suturing the 'loose' disk to the periosteum. Shore (1959) stated: "Temporomandibular joint arthrosis makes up 90% of all dysfunctions of this structure. The remaining 10% is accounted for by external trauma, i.e., fractures and contusions, and diseases which affect the joint.". He defined temporomandibular joint arthrosis as:

"A noninfectious, trophic, degenerative affection of the joint tissues initiated by intrinsic trauma and causing abnormal changes in the function of the joint."

Foged (1949) described joint sounds as follows:

"This lesion is usually called temporomandibular cracking, snapping joint, machoire a ressort, or Kiefergelenkknacken, which names, however, denote only one of the symptoms."

Sarnat (1951) classified TMJ disturbances as either congenital, inflammatory, traumatic, or neoplastic in nature. Brodie in 1951 related to the diagnosis of abnormal joint conditions and believed that the stethoscope.... "is one of the best ways to determine the exact stage of opening or closing when deflection occurs". Brodie also felt that stethoscopy...."yields suggestion on the state of the articulating surfaces". He also noted that x-ray examination was often of little diagnostic value.
Ireland (1951) listed as the symptoms and clinical findings of TMJ disturbances the following:

1. Painless clicking in the opening phase.
2. Intermittent "locking" - painful to open any wider than a fingerbreadth.
3. Limitation of opening with history of previous symptoms.
4. Limitation of opening without previous symptoms.
5. "Clicking, or more accurately jolting, at maximum opening and again at the beginning of the closing phase."
6. Combination of 1, 2, and 5 above.

Ireland further said that he observed clicking to suddenly begin in the late teens or early 20's or after some trauma or injury. The author felt that clicking comes at the beginning of opening and throughout the rest of opening, but closure is usually free of noises. He observed that the majority of his patients with TMJ dysfunction had deep overbite resembling that of Angle's Class II, Division II malocclusion. Often the molars were missing and the patients had a large freeway space. The author further observed that radiographically the condyle appeared to be posterior to normal and there was a noticeable backward
movement of the condyle as the patient moved from rest to centric occlusion. King (1963) substantiated Ireland's findings in a investigation of "diagnostically significant crepitus". King stated:

"The presence of crepitus in the temporomandibular joint seems to be related to the need for repositioning of the mandible in a particular patient."

T.M.J. PHONOGRAMS:

Ekensten (1952) criticized TMJ diagnostic techniques saying that in all cases an objective picture is not given. In no way could there be a predictable or predetermined treatment time. Ekensten also said that x-ray techniques were not reliable and could not explain what happened during the dynamics of functional movements of opening and closing the mandible. In his study a crystal microphone applied to the tuberculum articolare of the os temporale or to the os zygomaticus was used to record the TMJ sounds of 35 patients during opening and closing movements. The author felt that bone conduction of sound was better than muscle conduction. The crystal microphone used in his investigation picked up sounds only from objects that it was immediately contacting; therefore, extraneous background
noises such as heart beats, gastric sounds, etc. were not registered in his recordings. The sound signals were amplified by a low frequency pre-amplifier and then fed into an oscilloscope. A camera attached to the oscilloscope photographed the signals. Thus a permanent record was made possible and the subjectivity of diagnosis was eliminated. The author also made the point that the photographic records could be logged for future reference; therefore, objective testimony was available of the success or failure of treatment. It was found that.... "a physiological joint, having no anomalies, does not register any acoustic phenomena". The author also analyzed a joint with known subluxation and observed.... "from identity of sound waves one concludes that the anomaly has a definite characteristic which is revealed by the phonogram". The phonograms revealed the following:

1. The first small waves on the phonogram are the opening of the lips.

2. Smaller waves before larger waves are produced by the motion of the condyle against a non-physiological meniscus. Subluxations were caused by "lesion in the Menisc".

3. Large waves are subluxations.
4. The distance from wave top to wave top in one case was .02 seconds. Therefore, in that case the subluxation itself takes place in approximately one-hundredth of a second.

5. Each joint analyzed separately showed characteristic wave-forms with a phase shift of 180°.

**MECHANISM OF CLICKING AND ANATOMIC DESCRIPTIONS:**

Rees (1954) gave an anatomical description of the temporomandibular articulation based on his dissections of 12 postmortem subjects showing no evidence of TMJ arthrosis. He stated that clicking has as its cause excessive protrusive opening...."the condylar ridge slips forward (with a jump in some people which may produce a 'clicking' sound) over the anterior transverse band". The anterior transverse band was the author's name for the forward thickening of the meniscus. Rees further described the intermediate zone, posterior band, and the bilaminar zone (posterior disc attachment).

Sicher (1955) divided traumatic and degenerative disorders of the TMJ into subjective and objective symptoms. Subjective symptoms include pain, stiffness or feeling of tiredness of the masticatory musculature; whereas, objective symptoms include soreness of joint musculature,
limited mobility, ...."snapping or rubbing noises" in the articulation. Sicher observed that the pathologic changes in the joints were degenerative in nature and were localized in the fibrous coverings of the articular eminence and mandibular condyle and the articular disc. Sicher felt that the etiology was either overclosure, mandibular displacement, or bruxism. Anatomically there was a loose nature of the disc attachment to the posterior capsule. Sicher also noted that the loose connective tissue between the disc and posterior capsule is the point of lowest resistance and, therefore, most susceptible region for mechanical damage of the TMJ.

Campbell (1955) observed that the temporomandibular joint can click in any phase of mandibular opening, early middle, or late. He felt that the cause of this phenomenon was an abnormally displaced condyle. Campbell said: "It is easy to infer the cause of displacement as abnormal mastication.". He also believed that decreased vertical dimension (mandibular overclosure) was the cause of joint clicking. Silencing of the clicking was accomplished by increasing a patient's vertical dimension.
The author said: "A persistent click can often be silenced by raising the occlusal level sufficiently."

Vaughn (1955) stated when listening to other joints of the body via a stethoscope you will..."find that most joints have an operating sound which does not invade the conscious perception of the patient". He also said that the mandibular..."condyle can be protracted over and beyond the anterior border of the meniscus, and that the lateral anterior edge of the meniscus can be contused.".... "this protraction accounts for the bumping one feels during mandibular guide". Vaughn believed: "The eminentia is not the anterior limit of movement in all patients, especially those with shallow fossa.". He also said loud clicking was the result of fluid collection between tendons, adjacent bony parts, and the facial sheaths. An anatomically related phenomenon would be pretibial swellings, which have been reported to emit an audible sound up to a distance of 10 to 15 feet. Therefore, Vaughn concluded that temporomandibular joint sound could be the result of fluid collection in and around the capsular area.
CINEFLUOROGRAPHY AND T.M.J. DYSFUNCTION:

Berry and Hoffman (1956) conducted a cinefluorographic investigation of the temporomandibular joints and devised a microphone to pick up joint sounds. They observed that a click occurred during the initial phase of closing movement. They also formulated some treatment objectives which were as follows:

1. Reassure the patient that clicking is a benign symptom.
2. Evaluate the patient's motivation.
3. Exercise can be helpful.
4. Prosthetic devices can be fabricated to limit the range of mandibular opening.
5. Selective alteration of the occlusion.

MUSCLE DYSFUNCTION:

Swartz (1959) stated: "Our clinical investigations support the view that clicking is caused by muscle dysfunction." Out of 377 patients studied 36% presented symptoms of the "incoordination phase" of TMJ dysfunction. The so-called "incoordination phase" includes clicking, subluxation, and dislocation. Swartz found that 70% of these patients did have definite clicking sounds and the
three symptoms of the "incoordination phase" varied in duration from one week to 18 years. The patients associated the onset of their symptoms with the following:

1. Wide opening as in yawning.
2. A "slipping of the jaw" during a wide bite or vigorous chewing.
3. Following or during orthodontic treatment, particularly after the application of inter-maxillary elastics.

Shore (1959) strongly emphasized the "quartet of compensation" which is the 4 components of the stomatognathic system. These 4 components are the teeth, the periodontium, the temporomandibular joint, and the neuromuscular system. It was emphasized that the weak link in the quartet is the point of least resistance. In some cases the temporomandibular joints were the weak link and a resultant pathologic process ensued. Shore enumerated in the order of usual occurrence the clinical manifestations of temporomandibular joint arthrosis: "clicking, crackling noises, crepitation, tenderness, pain in and around the joint". He further stated that "the neuromuscular manifestations include limited mandibular movements with or without pain, difficulty on opening in the morning,
mandibular lock in certain positions on opening, compensation of the contralateral joint by hypermobility, subluxation, irregular mandibular opening and closing movements, condylar hypermobility, muscular dysfunction, muscle tenderness and spasm and the infrequent swelling in the preauricular area.

OCCLUSOGRAMS:

Brenman and Millsap (1959) studied the sounds of teeth coming together utilizing a microphone mounted on the forehead of their subjects. The sounds were stored on tape and transcribed to a visual form via an oscilloscope. The authors also photographed the oscilloscope screen and called their visual displays "occlusograms". An effort was made to differentiate a solid clinical centric occlusion from an unbalanced eccentric occlusion by differentiation of the sounds elicited when the teeth come together. The authors noted a significant difference of recordings of patients in different body positions. Whether the patient was in an erect or supine position varied the signals so the head was oriented by using a device developed by Dr. C. Jerge. Jerge's device had two arms
that paralleled the ala tragus line bilaterally and two
parallel arms that rest upon the shoulders. Recordings
were made with the patients sitting erect, sitting at
45°, and lying supine. The authors gave a good description
of sound wave forms and their relative clinical significance.
Sharp well-delineated sounds appear as smooth continuous
wave forms whereas discordant single sounds (such as a
cymbol crash or a pane of glass breaking) appear as
haphazard unsymmetrical wave forms. It was found that
patients presenting occlusal discrepancies displayed
sound wave patterns of an erratic nature with high amplitude
(rough grating sounds). Patients having a good sharp
centric contact free of centric slide displayed an
occlusogram with erratic wave forms of lower amplitude.
It was found that discordant occlusograms were reproducible
and the authors felt "that the recording and visual
display of sounds of dental occlusion is a valid premise".
It was also concluded: "The utilization of occlusal wave
patterns, presently at the research level, affords the
opportunity to obtain objective serial data for the study
of one phase of the mechanism of human dental occlusion.".
Bell (1960) said joint noise was the result of "failure of disc adaptability". He observed that many joints would emit sounds of various types when moved into extended ranges. Bell stated: "Excessive condyle movement quite frequently is accompanied by noise."

**MASTICATORY FORCE DISTRIBUTION PATTERNS:**

Conant (1962) investigated TMJ sounds and masticatory force distribution. One experiment involved the recording of sounds over the temporomandibular joints of 11 patients. Conant found a definite recurring pattern of the amplitudes recorded...."which appeared to be related to the chewing cycle". The author observed in the preceding experiment that it was difficult to determine the origin of sounds; that is, if the sounds emitted were TMJ sounds, food sounds, tooth sounds, etc.. In Conant's next experiment 24 subjects were analyzed for sound transmission in relation to masticatory force distribution patterns. This time a single microphone was placed against the inferior border of the mandible in the area of the mandibular symphysis. A signal generator connected to a transducer lead was placed on the patient's forehead to create a constant signal with a frequency of 1,000 cycles per second as a sound marker.
The introduced 1,000 cycle note as well as sounds of mastication were then recorded. Next the sounds were fed through a band-pass filter that eliminated sounds not in the 1,000 cycle range. A Sanborn model 150-400, direct current, two channel recorder received the filtered vibrations and made subsequent tracings on heat-sensitive paper. Conant analyzed lateral excursive patterns, centric position, and balancing side patterns (bolus side) by this method. A telegraph key was used as a reference-marker at significant points in each cycle so the aforementioned could be related to points on the recording. In other words, each time the teeth came into occlusion or the patient made lateral excursions the signal key could be depressed to mark the time of the event. Functional occlusal forces were studied in this manner on 24 subjects having normal appearing occlusions, free of any symptomology. None of the patients had any missing teeth or periodontal disease. In a preliminary test a pressure indication gauge was fastened to the teeth of one individual, and simultaneous tracing of sounds transmitted, during opening and closing, was recorded. Conant observed that the
greater the biting force, the higher the amplitude peak in the tracing. There was a linear relationship between pressure and peak in the tracing. For example, 10 pounds of intraoral pressure produced an 1/2 inch peak, and a pressure of 20 pounds produced a 1 inch peak, and so forth. Therefore, Conant was able to relate masticatory force distribution to sound transmission. The author stated that the primary purpose of his study was to design and test this procedure for studying force distributions, but three interesting observations were enumerated:

1. There was a stair-step reduction in chewing force recorded during early crushing of the foodstuff which the author interpreted as graphically illustrating how the periodontal proprioception mechanism "directs the use of only enough force to overcome the resistance of the bolus".

2. Centric position was found to be the point of maximum contact when soft foods were chewed lightly. Lateral shearing movements has its heaviest force in lateral excursive position and balancing position (bolus side) after leaving centric position.

3. Unilateral chewers have tracings that were often mirror images (180° phase change in amplitude plots). Bilateral chewers able to chew with equal facility on either side tend to have symmetrical patterns.
AUSSCULTATION OF THE MASTICATORY MECHANISM:

Watt (1962) stressed the importance of being cogniscent of auscultation of the masticatory mechanism. The author described a method of...."substituting a microphone for the chestpiece of the stethoscope so the sounds could be recorded on tape or visualized and photographed on an oscilloscope". Watt stated: "as each change in the oscilloscope trace is observed, and as the function of the temporomandibular joint improves, changes in the joint sounds can be heard and recorded". The author in this preliminary study concluded that the best position for recording joint sounds was just below the orbits (infra-orbital position) and that sounds of occlusion are characteristic for different individuals and are reproducible. Watt also said that the presence of 'hard crepitus'...."is almost diagnostic of temporomandibular joint arthrosis, and in its absence it is wise to look elsewhere for the cause of the symptoms unless there is a history of recent trauma". Watt also said that clicking sounds can be heard in a number of individuals with no temporomandibular joint trouble, but certain 'cracking clicking' which occurs early in opening
may be indicative of trouble in the joints.

Freese and Schemann (1962) also noted that with practice it was possible to produce some of the clicking sounds mentioned in the normal patient by bizarre manipulation of the mandible in opening and closing. The authors also noted that...."in patients whose mandibular movements are accompanied by sounds, a firm grip on the mandible to guide its movement so that deviation from the midline during slow opening is rendered difficult results in no sound and often there is no pain when this is the presiding symptom". It was suggested that the treatment of choice for such symptoms consists of retraining the musculature so they could function in a coordinated manner. Freese and Schemann felt that early diagnosis was the key to successful treatment. It was stated: "Early diagnosis is facilitated by auscultation of the joint to detect typical sounds of joint dysfunction".

King (1963) considered temporomandibular crepitus to be diagnostically significant. He said that crepitus can be considered pathologic and its presence might be interpreted as indication of abnormality in the function
of the stomatognathic system which can no doubt be considered a reflection of disharmony in the size, form, and/or position of one or more parts of the system. King defined crepitus as..."the audible or inaudible, palpable or non-palpable cracking or popping, occurring in the functioning temporomandibular joint". King mainly dwelled on the "most retruded crepitus" which he said was one single sharp pop or crack, or it might be described as a crackle or crunch. The author also said: "The presence of crepitus in the temporomandibular joint seems to be related to the need for repositioning of the mandible in a particular patient". King believed the cause of crepitus to be: "The movement of the condyle across the posterior border of the meniscus or articular disc...". To eliminate this condition the author felt that a repositioning of the mandible so that all the teeth contacted simultaneously upon closure with no resultant mandibular displacement was the treatment goal. King felt that this could be accomplished with proper orthodontic therapy.

Kelly and Goodfriend (1964) and Monson (1920) correlated temporomandibular disharmony with concurrent
problems of the auditory area. Monson attributed the pain associated with ear infection to joint dysfunction. Kelly and Good friend associated joint problems with vertigo and proposed to treat this condition with cast metal overlays. They stated: "In patients in whom the overlays relieved the vertigo, it usually relieved the crepitic and abnormal joint and jaw movements."

These men felt that mandibular overclosure was the etiology of joint dysfunction.

Ramsey (1964) stated that the cardinal signs of temporomandibular disorders are: "pain, limitation of movement, clicking or crepitus, and deviation of the mandibular midline, often accompanied by occlusal dis-harmony...". He felt that most TMJ problems were of traumatic origin and that the popping of clicking sound was caused by a disharmony of the "disc-condyle relationship". His treatment of choice was voluntary limitation.

**ARTHROSONIC AND OCCLUSONIC TRACES:**

Watt (1956) stressed the limitations and inaccuracies of detecting deflective occlusal contacts with articulated models. A technique of direct occlusal analysis utilizing
a central bearing point appliance which could be raised and lowered in 0.025 mm increments. Visual records of sounds with and without the appliance were obtained. Ideally, these should be identical with a slight allowance for change in resonance due to the appliance in the mouth. Watt recorded the sounds made in centric and eccentric positions with the bearing point elevated to take the teeth out of occlusion. It was concluded from this investigation that there is less error in this method of occlusal analysis than from articulator analysis.

Watt (1966) recorded occlusal sounds using his earlier techniques, but played the tape recordings through an Oscillomink paper recorder (Ferrograph recorder, British Ferrograph Recorder Co., Ltd., London). The author designated these records on paper of TMJ sounds as "arthrosonic traces" and records of occlusal sounds as "occlusonic traces". The microphones that were used in this study recorded primarily signals between 300 and 3000 cycles per second.

Ramfjord and Hiniker (1966) carried out a histologic investigation of effects of intentional distal mandibular
displacement in the Rhesus monkey. It was attempted to simulate the same effect as the loss of posterior teeth or the effect of distal displacement caused by Class III intermaxillary elastics used orthodontically. Utilization of splints combined with reduction of the occlusal tables of the posterior teeth prevented anterior occlusal guidance of the mandible. The significant finding in this study was that roentgenographic study of the monkeys' temporomandibular joints failed to reveal any pathologic changes; whereas, histologic examination of the condylar area in the 2 week experimental animal showed evidence of mild degenerative temporomandibular arthritis. The 8 and 16 week animals showed considerable bone resorption in stressed areas, but in the animal that was subjected to stress for a comparable period of time and then having the distalization discontinued showed a complete reversal of the posterior displacement. The authors had showed that the temporomandibular joints are anatomically stable. They attributed this finding to the basic anatomic and functional relationship between the muscles and the temporomandibular joints. Ramfjord and Hiniker concluded:
"It appeared that muscle balance was the most important factor in stabilization of jaw relationships.". In another article (1966) essentially repeating the former methodology, except in studying the effects of anteriorization of the mandible, they found some evidence of mild traumatic injury to the joints, but these changes were insignificant, non-progressive, and possibly reversible with treatment. The authors concluded that it is important to adapt the occlusion to the TMJ rather than hoping for the joints to adapt to the occlusion.

Gold (1966) reported that 10 to 15 patients with myotonia and 2 with amyotrophic lateral sclerosis had symptoms of joint dysfunction. Seven of these patients had history of clicking or locking of the jaws. He stated that myotonic muscular dystrophy may cause more TMJ disturbances than other muscular dystrophies.

Posselt (1968) stated that the human TMJ attains full development at about 20-25 years of age. He found clicking, pain and limitation of movement in an overwhelming percentage of the patients. The most frequent and obvious symptom was found to be clicking. When
clicking is present. Posselt noted that special attention should be paid to midline deviations. Freese and Schemann (1962) also supported this observation in their investigations.

Ross (1970) stated that the most common cause of TMJ pain and dysfunction is destructive occlusal force. Granger (1959) listed destructive forces as:

1. "premature contact in retruded contact position,
2. interference from balancing cusps,
3. interlocking between steep maxillary and mandibular cusps,
4. unilateral mastication,
5. a cross-bite relation, or
6. some other occlusal disharmony".

Ross also said that when teeth do not occlude evenly a dull sound is heard as the maxillary and mandibular teeth contact in intercuspal position.

ANKYLOSING SPONDYLITIS:

Crum and Loiselle (1971) observed in four of 26 patients with ankylosing spondylitis the occurrence of severe temporomandibular joint symptoms. Ankylosing spondylitis is thought to be a variant of rheumatoid arthritis in which there is chronic inflammation of the
sacroiliac joints with concomittant peripheral joint involvement in 10% to 30% of the patients. The 4 patients observed had...."history of or presence of TMJ pain, tenderness, swelling, or restricted motion; evidence of noise in the temporomandibular joints; presence of tinnitus; and evidence of bruxism". The patients were treated with interocclusal maxillary acrylic splints and with regular equilibration of the splints the pain and tenderness gradually decreased. An interesting observation was the patients' limitation of jaw movement decreased with treatment. The maximum interincisal distance before treatment was in the range of 23 mm to 32 mm and after treatment an average of 43 mm (range 23 mm to 61 mm). Crum and Loiselle also noted that the degree of postural imbalance of the head and neck affects the function of the masticatory system. They noted:

"The postural effects of this disease, as well as, the results of this study, support this impression; temporomandibular joint symptoms may be a consequence of the posture and not the disease. The manifestation of TMJ symptoms may be related to temporomandibular joint dysfunction caused by muscle spasm, occlusal factors, and postural imbalance of the head and neck."
MORPHOLOGIC, ANATOMIC, AND FUNCTIONAL CONSIDERATIONS:

Many authors have investigated the temporomandibular joint from a morphological and functional standpoint. Some have related joint sounds to the morphological composition of the "condyle-meniscus-pterygoid complex" (Rees, 1954; Sicher, 1955; Vaughn, 1955; Shore, 1959; Bell, 1960; King, 1962; Freese and Schemann, 1962; Ramsey, 1964; and others). The following is a concise review of a few morphologic, anatomical and functional considerations that the writer feels is significant to this investigation.

Schuyler (1947) said that it is difficult to differentiate a normal joint from an abnormal joint or to differentiate what may be considered normal for that particular patient. Function may have been the determining factor in development or formation of the joint; therefore, it is possible that one may have two slightly dissimilar joints with neither being pathological. If pain is present, then serious consideration must be given to abnormal appearing radiographs, in a differential diagnosis. Thompson (1954) said that clicking, crepitus, irregular mandibular movement, strain and fatigue of the mandibular musculature and subluxation added to differential diagnostic
data in evaluating joint dysfunction.

Ricketts (1950) examined the morphologic and functional variations of the TMJ as revealed by cephalometric laminography. He noted:

"Probably the most arresting concept gained form this study is the great range in variation found in practically every aspect investigated. The findings emphasize, to the writer at least, the danger of accepting conclusions based on average values or from methods that do not accurately reveal conditions in the living. Isolated cases could lead the investigator to believe many dogmatic statements concerning the subject, but when a large sample is studied there is scarcely a single generalization that holds."

Ricketts also observed:

"The almost total lack of correlation found between size of condyle and size of fossa does not support the idea that form and function, as generally considered, go hand in hand (Tomes and Dolomore, 1901; Harris, 1938; Breitner, 1941; Moses, 1946.) All evidence pointed to a relatively high degree of independence between the two."

Sicher (1955) noted that the meniscus is attached to both the medial and lateral poles of the condyle by strong and tight fibers that remain taut in all functional movements of the mandible. Therefore, the disc follows passively all sliding movements of the mandible and, in his opinion, the external pterygoid muscle is not directly
responsible for forward movement of the disc. Sicher concluded that the upper head of the external pterygoid muscle is not designed to bring about movement, but has as its function mainatance of balance and to keep the disc in contact with the temporal bone in a forward position on the oblique slope of the articular eminence.

The "mandibular functional unit" consisting of the masseter, internal pterygoid, temporal, external pterygoid, digastric, geniohyoid and mylohyoid muscles as described by Sicher allows mandibular movement to occur. These muscles were considered the movers, positioners, and balancers of the maxillomandibular apparatus. Sensory and motor feedback originating in the muscle spindles of the periodontal membrane, tendons, and ligaments of the joints operate the regulatory mechanism of smooth mandibular function. Sicher believed that any aberration, even a slight one, from the normal alignment of the teeth will bring about a discordant note in the otherwise harmonious chord of stimuli. He also contended that proprioceptive imbalance was caused by overclosure, premature contacts, and/or mental tension which could lead to muscle spasm
and joint noise. Muscle spasm eventually causes an actual displacement of the disc. The pain associated with the above phenomenon was believed by Sicher to be a result of impingement of the condylar head on the loose connective tissue behind the disc. Pain in the surrounding area was thought to be of primarily muscle origin.

Moss (1959) said the concave articular fossa was not necessarily a functional component of the temporomandibular joint. He considered the glenoid fossa as just a receptacle for the condyle when the jaws are approximated. The formation of this receptacle is, in Moss's opinion, related to the derivation of the external auditory meatus. Moss who has put forth his "functional matrix theory" noted that the cartilagenous coverings of other diarthroidal joints are functionally suitable in withstanding compressive forces. He said the fibrous connective tissue in the temporomandibular joints is especially designed by nature to withstand the shear forces of lateral movements.

Emmering (1967) did a radiographic study of the temporomandibular joints and devised a classification of the condyle-eminential complex. By using the Subzygomatic
Radiographic technique, Emmering classified the joints morphologically into four types of condyle-eminence relationships. Condyle-ementia complexes range from having a flattened superior condyle and ementia surface to round surfaced articulations, etc. The point made was that the TMJ area could be anatomically and morphologically classified into four basic relationships.

Functional anatomy and physiology of the temporomandibular joints has been briefly covered in the literature review and for additional material the reader is directed to the writings of Kawamura (1967, 1968); Posselt (1968); Ramfjord and Ash (1966); Ross (1970); Shore (1959); Schwartz (1959, 1968); Sicher (1951, 1954, 1955, 1965); and Thompson (1946, 1951, 1954).

ELECTRO.MYOGRAPHICAL INVESTIGATIONS AS RELATED TO T.M.J. PATHOSIS:

There is a wealth of material written on the subject of electromyography. The following is a resume' of a few related studies that can be applied or of importance to this investigation.

Jarabak (1956) said: "Functional disorders of the temporomandibular joint characterized by clicking, crepitus,
Trismus and pain are sufficiently prevalent to warrant physiological analysis." An electromyographic investigation was carried out using a group of patients that had a clicking or had developed a clicking in the joint during orthodontic therapy. Jarabak noticed: "At a point in the reduction of a distocclusion with intermaxillary elastics some orthodontic patients develop a resounding click in one or both temporomandibular joints." Jarabak concluded: "Functional disturbances in the temporomandibular joint may have their etiology in occlusal interferences of the teeth."

Moyers (1950) studied the musculature of the TMJ by electromyographic analysis. Moyers studied the temporalis, masseter, internal pterygoid, external pterygoid, and suprahyoid muscles. Subjects studied were free of temporomandibular articulatory difficulties and had normal occlusions. Electromyographic data was collected while the mandible was in physiologic rest position and while in functional movement. Moyers noted that when mandibular opening is initiated the first high amplitude action potentials were seen in the external pterygoid muscle. The author said: "The mean total time for this movement
was 2.89 seconds (range, 0.80-4.84 seconds; S.D. 1.25; S.E. mean 0.0536)." It was also observed that the internal pterygoid, masseter, and temporal muscles all display high amplitude spiking during elevation of the mandible.

Moyers found that the depressors of the mandible are both the suprhyoids and the external pterygoid. He stated: "It can be concluded that the external pterygoid is more responsible for the initiation of mandibular depression but that the digastric plays an important role in completing the movement." An interesting conclusion of Moyer's study was: "No changes are seen in the function of the various temporomandibular muscles from the time of the deciduous dentition to adulthood, except occasional transitory alterations in the internal ptergoid and temporal muscles. These occur as a reflex attempt to avoid malposed deciduous teeth in the process of exfoliation."

Moyers (1956) noted in another electromyographic investigation of physiologic jaw relations that mandibular movement is a highly coordinated pattern of synergy. That is, if the muscles of one side of the facial complex contract the contralateral side will react accordingly.
Eccentric mandibular positions are learned as expedient mechanisms for avoiding occlusal disharmonies. Moyers believed that abnormal reflexes evident electromyographically were caused by loss of tooth structure. It was stated that eccentric position of the mandible is directly related to the number of teeth lost. It was also mentioned that great temporomandibular joint mobility develops with eccentric occlusions. Centric relation was found to vary from patient to patient according to the subject's age, physical condition, or stage of dental development (mixed dentition versus permanent dentition). There was no convincing evidence that the most retruded position of the condyles from which lateral movements may be made coincides in all 1,100 patients. Moyers showed that 76% demonstrated muscle imbalance and strain when in centric relation. Moyers concluded that the position of the mandible is determined by a patient's neuromuscular mechanisms and not by the clinicians' paraphernalia.

Ingle (1957) attributed temporomandibular joint disturbances to directional deviations of the mandible as related to occlusal interferences. "Mandibular overclosure associated with posterior extractions, or condylar dis-
placement in any direction may thoroughly traumatize the condylar area. The resultant damage in the joint will be manifested by pain, referred pain, muscle trismus and often crepitus and cracking sounds emanating from the temporal fossa." Ingle emphasized the importance of palpation of the TMJ area and to confirm joint involvement the use of a stethoscope to determine which joint is the source of clicking or cracking sounds.

Perry (1957) conducted an electromyographic and cephalometric investigation of 126 subjects. Each subject was asked to show on a chart of the head the areas where pain was experienced due to temporomandibular joint dysfunction. This information was recorded and compiled into a composite chart. These areas were designated the regions of most prevalent pain occurrence. Electromyographic examination of these areas revealed the following:

"In all of the patients studied electromyographically, the pattern of muscle spasm closely followed the topographic distribution of subjectively recognized pain. This finding presented a definite basis for the dull, aching type of pain which was so characteristic in these patients."

Carter (1959) did an electromyographic investigation to study the influence of changes of head position in
relation to mandibular posture. The elevators and depressors of the mandible, as well as, the rotators of the head were studied. Carter found that the "stretch reflex" caused a firing of muscles when the head was moved from side to side when the mandible was in rest position. It was also mentioned that the time of day had a significant influence on onset of action potentials recorded. Carter stated: "Fatigue, stress, and apprehension are no doubt responsible for the muscular behavior observed."

Kawamura (1968) demonstrated by electromyograms that the relative spatial relationship of the disc and condyle is normally constant. The author determined this by monitoring the upper and lower heads of the external pterygoid muscles. Once the constant harmonious relationship is disturbed, the condylar head may collide with the leading or trailing edges of the meniscus producing a clicking sound. Freese and Schemann (1962) supported this view and classified joint sounds into 4 types. Clinically they observed the following four variations:

1. A single sound at the beginning of mandibular opening,
2. A single sound toward the end of mandibular opening and at the beginning of closure,
3. A single sound at the middle of opening and possibly another sound at the beginning of closing, and

4. A sound at the midpoint of opening, a second sound at the end of opening, and possibly a third sound at the beginning of closure.

INTRAORAL OCCLUSAL TELEMETRIC INVESTIGATIONS:

Glickman et al (1968) studied occlusion utilizing an intraoral occlusal telemetric analysis. By use of miniaturized electronic devices Glickman was able to detect which cusps and which teeth contacted during functional occlusion. Multifrequency transmitters were fabricated and built into removable and fixed prosthetic appliances. The transmitters sent three different frequencies, each frequency being related to different points of contact between the maxillary and mandibular teeth. The output frequencies of the intraoral transmitter were received and fed into a six-channel oscillograph recorder. Thus the authors were able to visually analyze the functional contacts during swallowing, chewing, or upon intentional occlusion. An interesting finding of a related study that followed was their investigation of centric relation. Centric relation is considered the border
position ordinarily reached by the mandible upon unstrained, most retruded, maximum closure. Deflective occlusal contacts are thought to prevent true centric related closure. Glickman's thesis was that if centric prematurities detected by intraoral occlusal telemetric analysis were eliminated, then, the patient should assume a centric relation as a functional position. It was found that the mere elimination of these prematurities did not result in increased use of centric relation.

Additional information regarding intraoral occlusal telemetry studies (Radiotelemetry) may be obtained by reading the works of Brewer and Hudson (1961); Gillings, Kohl, and Zander (1963); Graf and Zander (1963); Powell (1963); Adams and Zander (1964); and Scharer and Stallard (1965).

PHARMACOLOGIC AND THERAPEUTIC CONSIDERATIONS:

Gangorosa (1972) said that drug therapy can be useful in treatment of TMJ dysfunctions. Muscle spasms may be relieved by psychosedative agents, such as minor tranquilizers and sedatives. He discussed the relative muscle relaxant potencies of meprobamate (Miltown, Equanil),
methocarbimol (Robaxin), diazepam (Valium) and other CNS depressants. Gangorosa noted that good results have been obtained with the use of diazepam (Valium). Other pharmacological methods of treating severe spasms included local anesthetic block, neuromuscular junction block, and general anesthesia. It was also noted that arthritic conditions often warrant the use of intra-articular injections of steroids.

Gangorosa also noted that most causes of TMJ dysfunction are iatrogenic. The following were enumerated:

1. Occlusal Rehabilitation
2. Orthodontic therapy
3. Periodontal therapy
4. Anesthesiologist
5. Trauma
6. Arthritic conditions or a disposition to arthritis
7. 80% of the individuals have a psychogenic origin

Many authors feel that most TMJ problems are of psychosomatic origin. In fact, Mitchell (1972) said: "The majority of problems of the temporomandibular joint have a 'Nut' attached to them".
MISCELLANEOUS CONSIDERATIONS:

Some investigators have studied the temporomandibular joint bilaterally. McCollum (1943) as cited by Jacobsen (1960) found the following significant in his investigation:

"It can be demonstrated that the individual condyle path has a definite inclination and curvature. It is interesting to note that the inclination and the curvature of the condyle path in not necessarily the same for the two sides of the individual. It is interesting to note that the loci of the rotating condyles are not symmetrical. The lateral rotation locus of the right condyle is not correspondingly spaced to the rotation locus of the left condyle. A why should we expect these particular joints of the body to be bilaterally symmetrical, when the halves of the body throughout are more than apt to disagree."

Other investigators have studied the TMJ by observing and recording mandibular functional or simulated functional movements. Various and sundry apparatus have been employed to record so-called physiological jaw movements. Walker (1896) as cited by Jacobsen (1960) was the first investigator to register individuals jaw relations and movements of the mandible for the purpose of construction of an articulator to artificially simulate these movements. Studies that followed Walkers' investigation were Christensen (1901), Camion (1905), Prothero (1911), Bennett (1912),
Gysi (1930), Hanau (1930), Kurth (1942), McCollum (1943), and Posselt (1957). These investigations differed in many ways and were similar in other ways; but, all had in common study of the temporomandibular joint through mandibular movements.

A few roentgenographic studies of the temporomandibular joints have been previously mentioned. It should be mentioned that with the introduction of cephalometric radiography by Broadbent (1931) a vast amount of valuable information has been accumulated. Techniques used by Gillis (1935), Lindblom (1954), Higley (1936), as well as many others were great steps forward; but, the angulations required for unobscured radiographs did not free the films of distortions. It was not until the advent of body sectioning roentgenography or laminography as described by Bleiker (1938), and Petrilli's (1939) and Curley's (1939) tomographic technique that an unobscured distortion-free picture of the condyle-fossa relationship was available. Other laminographic investigations were conducted by Kieffer (1938), Brader (1949), Kurz (1943), Norgaard (1947), Ricketts (1950), Upedgrave (1950), and Donovan (1953).
All these investigations as those that followed have and will augment present knowledge of the function and morphology of the temporomandibular articulation.

However, Jacobsen (1960) said it should be understood:

1. Roentgenographic analysis of the joints can not identify initial tissue damage since soft tissue changes are not readily discernible on a radiograph of this area.

2. Pathology is hard to diagnose from simple changes in radiodensity.

3. Conventional roentgenograms are two dimensional pictures of three dimensional objects.
CHAPTER II

STATEMENT OF THE PROBLEM

It has been widely accepted that fingerprints will identify most individuals with great accuracy. This study will attempt to show that each individual also has a "TMJ sound print". The use of the Sonagraph manufactured by Kay Elemetric Corporation, Pinebrook, New Jersey, as a diagnostic instrument will be investigated.

The purpose of this investigation is to determine, from an objective standpoint, if temporomandibular joint sounds are diagnostically significant. An effort will be made to devise a standardized approach free of most variables to analyze sounds elicited by the TMJ. This will be a preliminary investigation to establish a norm "sonagraphic audio-spectral range" so that joint sounds thought to be pathologic can later be pinpointed visually on the sonagraphic display.
CHAPTER III
MATERIALS AND METHODS

SUBJECT SELECTION................Normal Group (Asymptomatic):

This investigation was carried out utilizing subjects selected from the student body, staff, and patients presenting themselves to Loyola University School of Dentistry. There were 21 caucasian subjects that ranged in age from 18 to 40 (mean age, 25.29) with the majority of the patients being young adults free of any known pathology or symptoms of the temporomandibular joint. All subjects of the normal group had Angle's Class I occlusion and were free of any past or present evidence of joint dysfunction. According to Edward H. Angle's (1899) static definition of Class I occlusion the anteroposterior relationship of the maxillary and mandibular molars is such that the mesiobuccal cusp of the maxillary first molar interdigitates in the buccal groove of the mandibular first molar. Graber (1966) felt that Angle's classification even though of static nature..."still serves a very useful purpose in describing the anteroposterior relationships of the maxillary and mandibular dental arches which usually reflect the jaw relationship". Each subject
in this investigation had what would be deemed, by most clinicians, a normal anteroposterior jaw relationship. Therefore, the subjects in the normal group had absence of any known skeletodental dysplasia and, in addition, were free of any myodysfunctional aberration or dysgnathic abnormality.

Histories and clinical examinations were taken on each patient to assure a normal status of the masticatory apparatus. Each patient was asked to fill out the following form regarding their general dental and physical health:
FIGURE I
PATIENT HISTORY FORM

Diagnosis Date________

Name________________________ Residence________________________
Phone________________________ Birth Date______ Age________

Please answer the following questions with a YES or NO. Comment on any positive answers.

1. Have you had previous or present history of..............
   Arthritis Osteoarthritis
   Rheumatoid arthritis Sinus infection
   Ear infection Allergies
   Swollen glands Blood Vessel Disease
   Pain in the right or left ear

2. Do you have frequent headaches?________ What area of the head?________ How long do they last?________
   Migrane?________ Other comments________

3. Have you ever had a severe blow to the head?________
   What part of the head?________ Date?________
   Have you ever been hit on the jaw?________ Date?________

4. Do you have any current non-dental physical problems?________
   If so, please describe them:________

5. Do you have any emotional problems regarding your teeth?________

6. Do you have any current dental problems?________

7. Do you clench, grind, or brux your teeth?________

8. Do you ever feel pressure or tenderness in front of your ears?________

9. In which ear (R or L) do you ever notice: Ringing_____
   Popping noises ______ Stiffness____ Pain____
   Itchy feeling________ Other________
10. Have you ever been told that you have temporomandibular joint dysfunction?

11. Is there a family history of temporomandibular joint dysfunction?

12. Have you ever been treated by an orthodontist or periodontist?

Signature
Date
CLINICAL EXAMINATION........... Normal Group (Asymptomatic):

Each subject was given a brief physical and dental examination using a uniform clinical examination form (Fig. 2). The subject's sex, race, stature and body weight were determined and recorded on the exam form. A physical examination of the stomatognathic musculature was performed with an effort to pick up any muscle aberrations. Patients having any positive symptomology indicative of potential or acute temporomandibular pathology were automatically eliminated from the normal group. Each subject's body type was classified as endomorphic, ectomorphic, or mesomorphic; as well as, classification of their relative facial type as brachycephalic, mesocephalic, or dolichocephalic. A routine dental examination was carried out having as its purpose the elimination of any subject that exhibited any deflective occlusal contacts. During this part of the examination the overbite, overjet, and maximum unstrained interincisal distances were determined. Each subject was also instructed to go through functional mandibular movements (right lateral, left lateral, and protrusive)
---48---

FIGURE 2

CLINICAL EXAMINATION FORM

Diagnosis Date

<table>
<thead>
<tr>
<th>Patient's Name</th>
<th>Sex</th>
<th>Race</th>
<th>Weight</th>
<th>Height</th>
<th>Birth date and age</th>
</tr>
</thead>
</table>

A. Patient History (Positive + Negative -)

Comments:

B. Muscle Examination: (Tenderness and/or pain upon palpation) + or -

- Temporalis
- Masseter
- External Pterygoid
- Internal Pterygoid
- Infrahyoid and Suprahyoid
- Hypertrophy of any muscle
- Other muscle involvement

C. Body Type:
1. Endomorph
2. Mesomorph
3. Ectomorph

D. Facial Type:
1. Brachycephalic
2. Doliocephalic
3. Mesocephalic

E. Dental Examination:
1. Molar Relation (Angle) I II or III
2. Canine Relation (Simon) I II or III
3. Deflective Occlusal Contacts......
   - centric
   - protrusive
   - right lateral
   - left lateral
4. Attrition
5. Mobility
6. Overbite (mm)
   - Overjet (mm)
F. Mandibular Movements:

1. Path of Closure:
   Deviation........Right (mm)______Left (mm)______

2. Abnormal Condyle Movement Revealed Upon Palpation
   a. hypermobility of condyle____________________
   b. hypomobility of condyle____________________
   c. dislocation of condyle______________________
   d. subluxation of condyle______________________
   e. clicking upon opening_______________________
   f. clicking upon closure_______________________
   g. crepitus upon opening_____________________  
   h. crepitus upon closure______________________

G. Pain of TMJ upon pressure:____________________

H. Swelling of TMJ Area:________________________

I. Roentgenographic Evaluation:________________________
   ______________________________________________
   ______________________________________________
   ______________________________________________

J. Maximum Interocclusal Distance: (mm)_______________

K. Other Positive Clinical Findings:________________________
   ______________________________________________
   ______________________________________________
   ______________________________________________
   ______________________________________________
with emphasis on the presence of abnormal condylar movement as revealed upon palpation. Again any aberration was noted and the subject was not considered normal.

The majority of subjects used in this investigation were part of a concurrent study of ideal, non-orthodontically treated, occlusions conducted by Loyola Department of Orthodontics. Most patients had a full complement of orthodontic records which included: 8 cephalometric roentgenograms, 1 panoramic x-ray, 16 periapical x-rays (Full mouth series), 5 facial and 7 intraoral kodachromes. A set of orthodontically trimmed models was made for each patient and included in the records. Evaluation of these records was done with an effort to assure that each subject fell within so-called "normal skeletodental limits". Any patients exhibiting deviation from accepted skeletodental averages were eliminated from the normal group. It should be kept in mind that norms are only group abstractions and that each individual has a certain amount of normal variation even though he or she has an anatomically excellent occlusion. Therefore, analysis of all orthodontic records was carried out as
objectively as possible with major emphasis on the absence of temporomandibular symptomology.

**ELECTRONIC AUSCULTATION OF THE T.M.J.:**

In an effort to analyze sounds emitted by functioning temporomandibular joints a method of pick-up, amplification, and recording these signals was devised. Bilateral crystal microphones of the hearing aid type were used to pick up joint sounds. Amplification and recording was accomplished by utilization of a stereophonic cassette tape recorder which will be described later.

**Air Conduction T.M. Microphones (Fig.3)**

It was the purpose of a six month pilot study to determine what type of microphone would yield the highest quality recordings with the elimination of extraneous background interferences. A group of 10 patients were tested using air conduction microphones. Subsequent recordings were quantitatively good; however, the qualitative value of these recordings was questionable. It was impossible to eliminate outside interferences in the recordings as the air phones pick up all sound in the immediate vicinity of the patients. The recording of the
FIGURE 3
AIR CONDUCTION MICROPHONES

Can only be used in a sound proof room. Recordings were of inferior quality; therefore, "Bone Conduction" microphones were substituted.
patients in a sound-proof room did not eliminate all exogenous noise. If the subject or examiner moved or if the examiner gave instructions to the subject, this would also be picked up by the microphones. Therefore, air conduction microphones were abandoned and another pick-up device was substituted.

Bone Conduction T.M. Microphones (Fig. 4)

Another pilot study of eight subjects utilizing bone conduction microphones was carried out. It was found that bone conduction (hearing aid type) microphones when placed over the right and left cheek bones yielded the best quality recordings. Bone conduction microphones picked up only those vibrations transmitted from the TMJ area through the bone structure. Only vibrations from the TM joints were picked up as the phones were not sensitive to air vibrations. These microphones enabled the operator to give voice commands to the subjects without interfering with the subsequent recordings. Therefore, bone conduction phones were the instrument of choice in this investigation.
Bone conduction phones (hearing aid type)
The instrument of choice in this investigation-
Mounted in adjustable headholder.
"Radio Operator's Type" Headset For Stabilization of T.M. Microphones.
A. Microphone Placement Marked Over The Os Zygomaticus
B. Microphone Placement Noted On The Dry Skull
on the recordings. The same effect occurred when the subject completed closure and the emporalis muscles bulged lateralward.

Benman and Millsap (1959) found that placement of a microphone on the forehead of their subjects eliminated the preceding phenomenon and yielded good quality recordings. Connant (1962) also used a single microphone placed against the inferior border of the mandible in the area of the mandibular symphysis. Then Watt (1962) observed that recordings of the sounds of occlusion could be obtained by placement of the microphones just below the orbits in the "infraorbital position". In the present investigation it was necessary to analyze the right and left joints concurrently and also as separate entities. Therefore, another position for the microphones was necessary.

In this investigation placement of the microphones was the same as that of Ekensten. Ekensten (1952) found that placement of the microphones over the os temporalis or os zygomaticus yielded recordings of good quality. Therefore, all recordings in the present investigation
A. Microphones In Place On Patient.
B. Sound Conducted To Phones Via The Zygomatic Arch.

(OR - Orbit; ZY - Zygomatic Arch; G - Glenoid Fossa)
were made with placement of the microphones on the os zygomaticus (cheek bone). The sounds produced by the TMJ were conducted through zygomatic arches to the phones (Fig. 7 & 8).

**Head Position Of The Patient**

It was shown by Vanocek (1957) that variation in mandibular position in relation to change in head position caused a change in the electrical activity of the muscles of mastication as evidenced by electromyographic analysis. Carter (1959) observed that rotation of the head altered mandibular posture and the elevators of the mandible seemed to resist this disturbance. Robinson (1966) stated that temporomandibular joint is analogous to spring hinges on a pair of swinging doors. He stated: "If the door frame, which might be compared to the temporal part of the joint, is level, the doors swing shut smoothly and evenly. It, however, this frame is tilted, the doors close unevenly because of gravity." Electromyographic evidence substantiated this analogy showing that the muscle firing pattern varied with postural influence. Kawamura (1968) also mentioned that head position can be
A. Microphones In Place Over Anterior Portion Of Zygomatic Arch On Patient (Close-Up).

B. Sound Is Conducted To Phones From Glenoid Fossa Via Zygomatic Arch.

(OR - Orbit; ZY - Zygomatic Arch)
a determining factor in mandibular movements. Interpretation of results are not accurate if this is not considered. Therefore, each patient tested was seated upright in a straight backed chair facing frontward. The subjects were instructed to look straight ahead or if necessary a reference point was placed on the wall in front of the patient. The reference point enabled the patient to keep his eyes straight ahead and paralleled the Frankfort horizontal (porion to orbitale) to the floor. It was important that this position be maintained throughout testing, However, it also had to be an unstrained position. Clinical observation by the examiner assured the unstrained maintance of this head position.

T.M.J. RECORDING TECHNIQUE:

Each patient included in this investigation underwent electronic auscultation of the right and left temporomandibular joints while making specific mandibular movements. Bilateral tape recordings were made of the following:

1. Opening-Closing Movement: Centric occlusion (start) to maximum opening to centric occlusion (finish). (Fig.9)
Patient Is Instructed To Open To His Or Her Maximum Unstrained Interincisal Distance.
In recording of opening and closing movements the patients were instructed to open to maximum unstrained interincisal distance and to complete the closure of the mandible until the teeth came into complete intercuspation (centric occlusion). The musculo-condylar sounds as well as the sounds of centric contact were recorded. At least 5 opening-closing movements were recorded for every patient.

In order to specifically mark the tape recordings at selected points in time the patients were instructed to say certain words. As previously mentioned, bone conducting microphones pick up all sound vibrations from those objects in direct contact. Therefore, any voice vibrations were also picked up on the tapes.

Upon completion of the recordings the maximum unstrained interincisal distance was measured in millimeters with a Mauser Gauge. (Fig.10) This information was recorded on the clinical exam form.

To insure that every patient understood the instructions they were given the following information:
SOUND ANALYSIS OF THE TEMPOROMANDIBULAR JOINTS

You are part of an investigation having as its purpose the study of sounds emitted from the joints between your upper and lower jaws when you open and close your mouth. In order to achieve the best recording results of your TEMPOROMANDIBULAR JOINTS please do the following:

1. When you are instructed, say your full NAME and today's DATE.
2. Say the word START; then, without straining open your lower jaw FIVE TIMES as wide as you can and close touching your teeth each time.
3. After five opening and closings say the word STOP. The first part of this study is complete.

SUMMARY: PART I

1. SAY NAME AND DATE.....
2. SAY START.....
3. OPEN AND CLOSE FIVE TIMES.....
4. SAY STOP.....
FIGURE 10
MAUSER GAUGE

Used to measure maximum unstrained inter-incisal distance.
SYMPTOMATIC GROUP (T.M.J. DYSFUNCTION SYNDROME):

A second group of 14 caucasian subjects that had one or more symptoms of temporomandibular joint dysfunction (clicking, trismum, pain, limitation of movement, etc.) were sonographically analyzed. Patients were selected from the faculty, staff, student body, and individuals that presented themselves to Loyola University School of Dentistry. Each patient was asked to fill out a history sheet (Fig.1) and had a thorough clinical examination (Fig.2). All procedure was identical to that of the normal group of subjects. Emphasis was placed on the patient's body type, facial type, evidence of cross-bite, history of trauma, age of the patient, missing teeth, allergy, bruxism, mandibular deviation, pain, and presence of dual bite. Many of the forementioned have been frequently mentioned in the literature either associated with or the cause of joint pathology. Due to the nature of this study, special attention was paid to patients who had either unilateral or bilateral crepitation of clicking. Each subject in this group was recorded using the same methodology as that of the normal group.
In certain cases a right and left laminograph or a series of cephalometric roentgenograms were included as part of the patient's records. All records were analyzed with an effort to determine the etiology of the TMJ pathosis.

It is not the purpose of this paper to present different therapeutic methodology, but to analyze objectively the sounds emanated by the temporomandibular joints of this group. However, some patients were treated by giving maxillary or mandibular full coverage splints (Shore, 1967); others, were given muscle relaxants (such as Valium) or tranquilizers (Maolate); or, the patients were instructed to voluntarily limit their mandibular activity. Other patients were equilibrated or referred to the fixed prosthetic department for occlusal rehabilitation. Of course, the method of treatment depended upon the severity of the case or the individual circumstances of the problem. So much for therapeutic methodology and again it should be noted that major emphasis will be on the sonagrams of this group.
Bilateral recordings of the temporomandibular joints were made with an Ampex Micro 70 cassette tape recorder. The Micro 70 was the instrument of choice since it gives one virtually distortion free, standardized recordings. By use of an automatic record level switch (Fig.12A) each patient tested was recorded at the same level. This was also substantiated by visually monitoring the right and left channels on the built-in VU meters (Fig.13). Another important feature of the Ampex Micro 70 was the ability of this instrument to be operated anywhere on self-contained batteries. When operated with line current (A.C.) the recordings had an abundance of background interference. Therefore, an effort to minimize exogenous interference was carried out by operating the recorder with battery power (Direct Current).

The instrument specifications that are applicable to this investigation are in the following chart (Fig.11):
FIGURE 11

CASSETTE RECORDER - SPECIFICATIONS

Power Input: Voltage; 117V, 60 Hz
Power Consumption: 20 W
Maximum Power Output: 0.8 Watt RMS/Channel @ 5% distortion
Frequency Response, Playback & Overall

Stereo Channel Separation: 40 to 10,000 Hz

Signal to Noise Ratio: 25 dB

Mic Input Sensitivity and Impedance

Line Input Sensitivity and Impedance

Adjustable Line Output Level - Impedance

Speed Accuracy + 3%

Flutter (play) 0.35% UNWTD RMS
FIGURE 12

A. AUTOMATIC RECORD LEVEL SWITCH.
B. STEREOPHONIC OUTPUT CABLES WHICH GO TO SONAGRAPHER.
TMJ recordings were standardized on the Sonagraph by observing the reading on the VU meter. The majority of sonagrams were made with the meter set at 20.
ANALYSIS OF T.M.J. SOUNDS:

The Sonagraph:

The sonagraph (Fig. 14) manufactured by Kay Elemetric Corporation, Pinebrook, New Jersey, is an audio-frequency spectrum analyzer that is capable of producing permanent, graphic recordings of any type of complex sound wave in the range of 5 to 16000 cycles/second (Hz). The sonagraph 7029-A allows the operator to analyze a sound recording in three dimensions. The No. 1 display (Fig. 15 & 16) gives a visual picture of frequency, amplitude and time simultaneously on a single graphic display.

Analysis of sound began with feeding input signals (TMJ sound recordings) into the sonagraph. The TMJ sounds which were previously recorded on cassette tapes were monitored and the portion of the recording warranting analysis was programmed into the sonagraph by a connection from the stereo output of the TMJ recorder to the input receptacle of the sonagraph (Fig. 17). The sonagraph has variable recording times and each time interval gives analysis of a specific frequency range. For example,
FIGURE 14

SONA-GRAPH 7029A
5-16,000 Hz AUDIO-SPECTRUM ANALYZER
if a 4.8 second TMJ recording is sonographically analyzed a frequency range of 40 to 4000 Hz is the limitation of the sonagram. The following is a frequency range chart of 5 to 16000 Hz in six ranges:

<table>
<thead>
<tr>
<th>FREQUENCY RANGES</th>
<th>RECORDING TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-500 Hz</td>
<td>38.4 Seconds</td>
</tr>
<tr>
<td>10-1000 Hz</td>
<td>19.2 Seconds</td>
</tr>
<tr>
<td>20-2000 Hz</td>
<td>9.6 Seconds</td>
</tr>
<tr>
<td>40-4000 Hz</td>
<td>4.8 Seconds</td>
</tr>
<tr>
<td>80-8000 Hz</td>
<td>2.4 Seconds</td>
</tr>
<tr>
<td>160-16000 Hz</td>
<td>1.2 Seconds</td>
</tr>
</tbody>
</table>

In this study a recording time of 4.8 seconds was used thus giving one a frequency range limitation of 40-4000 Hz. The effective frequency resolution at the given recording time was 22.5 to 150 Hz with a response of $\pm$ 2 decibels (dB) over the entire range. In other words, 4.8 seconds of an opening and closing movement of the mandible could be analyzed for any frequency in the range of 40 to 4000 Hz with an effective resolution in the range of 22.5 to 150 Hz and $\pm$ 2 dB accuracy.

After the specific TMJ sounds were fed into the sonagraph a continuous tape within the machine plays back the signals at high speed in order to scan the wave contents.
Sonagram showing the amplitude plot on the upper third of the tracing and the characteristic islands of gray representing frequencies present in a joint sound.
FIGURE 16

SONAGRAM - CLOSE-UP

Close-up of the stylus that burns tracing of sound components onto the heat sensitive Sonagram paper.
FIGURE 17
CASSETTE TAPE RECORDER
FOR
SONA-GRAPH 7029A

Stereophonic output cables are fed into the Sonagraph. Cassette recorder is also pictured above.
If desired a built-in calibration tone generator enabled the operator to mark the sonagram with a frequency scale in 50, 500, or 1000 Hz graduations. A graduated scale was inscribed on one side or the other of every sonagram having an appearance much like a ladder (see Fig. 18 & 19). In this study a 500 Hz scale was included on all sonagrams.

The sonagraph analyzed the TMJ recordings in 1.3 seconds giving one a paper graphic display that can become part of a patient's permanent record. Each paper display was analyzed for frequencies and amplitude as a function of time.

If one wanted to analyze a selected point on the sonagram for amplitude versus frequency the sectioner micrometer plate having 300 units, eight milliseconds can be utilized. Any section may be taken for signal analysis at any of these points. Applying the forementioned in a practical situation would involve the analysis of a preselected part of the opening and the closing movement of the mandible. For example, a TMJ click at the end of opening could be specifically analyzed for amplitude versus frequency.
Sonagraph drum with heat sensitive paper held in place with springs at the top and bottom. The drum rotates at high speed while a stylus burns a tracing of the audio-frequency components present.
Another feature of the sonagraph was its ability to separate the amplitudes of the TMJ recordings and graphically display it on the upper third of the normal sonagram. All recordings analyzed in this study showed the relative amplitudes at the top of the sonagram in relation to a baseline. (Fig.15)

In summary, the songaraph was capable of giving one a spectral analysis of a complex signal, breaking down the signal into each frequency component (up to 4000 Hz in this study) and revealing the level in decibels of each component (+ 2 dB) as a function of time. It was also noted that the sonagraph was capable of sectional analysis of any preselected point in time as well as giving one a separate amplitude plot at the upper one third of the sonagram.
Sonagraph Standardization:

A sonagram of the main (right side) and auxiliary (left side) channels of the sonagraph was performed to determine the amount of electrical background interference present. It can be seen in figure 19B that there is some electrical interference probably attributable to sixty cycle per second oscillation of 110 volt line current. It can be seen on the sonagram that whenever one depressed a switch, a spike or elevation resulted on the tracing. In order to transcribe data from stereo tape recordings to the sonagraph it was necessary to depress two "record-reproduce" switches simultaneously; one switch for the left channel and one for the right channel. Tracings of both channels have inscribed peak areas indicative of depressing these switches.

Above base lines on the standardization sonagram there is a continuous dark band that appeared in every subsequent tracing. This band was omitted from the data as it was assumed to be the result of line oscillation (A.C. line current).
FIGURE 19
STANDARDIZATION

Sonagraphic Picture of Tape Noise.

Sonagram of Sonagraph Void of Any Input Signal.
Tape Standardization:

Recordings of the right and left channels of a blank tape to be used in recording TMJ sounds was first analyzed by the sonagraph (Fig.19A). It was noted that a dark band 5 mm in height appeared immediately above the baseline of the test recording and all subsequent recordings. Again this was attributed to line interference (60 cycles/second). The upper amplitude tracing indicated that relative amplitude of tape noise is continuous and of constant intensity. The major portion of the sonagram appeared to be darkened with small islands of white indicating that no distinguishable frequencies were present on either channel of the blank tape. It was also observed that the depression of the reproduce-record switches disrupted the normal appearance of the sonagram (Fig.19A).
REPRODUCABILITY OF RECORDING TECHNIQUE:

Prior to collection of data in this investigation a pilot group of 7 patients were tested for reproducability of recording technique. Each subject was selected at random and had their right and left temporomandibular joints recorded two or three different times with a maximum time lapse of approximately 125 days between each recording session. Subjects were recorded under the same conditions and the recordings were analyzed with the Sonagraph so first recordings could be compared with subsequent recordings. The following subjects were tested for reproducability of recording technique:

<table>
<thead>
<tr>
<th>SUBJECT NUMBER</th>
<th>SEX</th>
<th>FIRST RECORDING</th>
<th>SECOND RECORDING</th>
<th>DAYS LAPSED</th>
<th>THIRD RECORDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 N*</td>
<td>M</td>
<td>8-14-71</td>
<td>10-25-71</td>
<td>102</td>
<td>2-29-72</td>
</tr>
<tr>
<td>06 N</td>
<td>M</td>
<td>9-3-71</td>
<td>10-15-71</td>
<td>42</td>
<td>3-09-72</td>
</tr>
<tr>
<td>07 N</td>
<td>F</td>
<td>10-13-71</td>
<td>11-16-71</td>
<td>33</td>
<td>3-17-72</td>
</tr>
<tr>
<td>09 N</td>
<td>F</td>
<td>9-3-71</td>
<td>10-26-71</td>
<td>53</td>
<td>3-09-72</td>
</tr>
<tr>
<td>19 N</td>
<td>M</td>
<td>11-5-71</td>
<td>3-11-72</td>
<td>128</td>
<td>-</td>
</tr>
<tr>
<td>20 N</td>
<td>M</td>
<td>8-18-71</td>
<td>10-19-71</td>
<td>62</td>
<td>2-29-72</td>
</tr>
<tr>
<td>13'P**</td>
<td>M</td>
<td>9-5-71</td>
<td>3-10-72</td>
<td>133</td>
<td>-</td>
</tr>
</tbody>
</table>

*N = Normal Group
**P = Pathologic Group
SONAGRAPh SETTINgS AND METHOdology OF tMJ sound analySIS:

For any one desiring to duplicate the technique or to add to the information of this investigation it is necessary to become familiar with the following:

1. Standard stereophonic connector cables are used to connect the tape recorder to the main and auxiliary channels of the Sonagraph. (Fig.17)

2. Monitoring the tape to be analyzed is done by adjusting the monitor volume control switch.

3. When TMJ sound warranting analysis is audible depress the Record-Off-Reproduce switch to the Record position. Due to a short time delay (2-3 seconds) it is possible to depress the switch after the sound to be analyzed is heard, and it is exactly reproduced on the recording heads of the Sonagraph. The TMJ sounds should be carefully monitored to assure that the Sonagraph's reproduction of the sounds is clear and the exact segment you desire to be analyzed.

4. A piece of Sonagram paper (5 5/8" X 12 3/4") is fixed around the drum of the Sonagraph (Fig.18) with the coated side facing outward.

5. The Record-Reproduce switch is turned to the Reproduce position which will start the drum revolving at high speed.

6. The stylus should be engaged into place at the bottom of the Sonagram and a tracing of the sound components will be burned into the heat sensitive paper.

7. After completion of the normal Sonagram tracing (Fig.15) an amplitude plot can be placed on the upper 1/3 of the Sonagram. Leave the first tracing
in place on the drum and trace over the upper 1/3 of the Sonagram, but use the Amplitude Display Unit 6070 A.

8. Tracings should be done for both the right (main channel) and left (auxiliary channel) temporomandibular joints. This may be accomplished by switching from the main channel to the auxiliary channel and repeating the above procedure with a new piece of sonagram paper.

The following settings were used in this investigation:

**SONAGRAM SETTINGS**

<table>
<thead>
<tr>
<th>Setting</th>
<th>Setting Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Switch</td>
<td>ON</td>
</tr>
<tr>
<td>Input Selector Switch</td>
<td>High Level Input</td>
</tr>
<tr>
<td>Sectioner Switch</td>
<td>OFF</td>
</tr>
<tr>
<td>Mark Level</td>
<td>5</td>
</tr>
<tr>
<td>(Contour Display Unit)</td>
<td></td>
</tr>
<tr>
<td>Record Level Switch</td>
<td>2 - (600 Ohms)</td>
</tr>
<tr>
<td>Reproduce Level Switch</td>
<td>Variable..set so VU meter</td>
</tr>
<tr>
<td></td>
<td>reads between -10 to -20...</td>
</tr>
<tr>
<td></td>
<td>(Provides as adjustment of the</td>
</tr>
<tr>
<td></td>
<td>reproduce amplifier gain, in 2 dB</td>
</tr>
<tr>
<td></td>
<td>increments)</td>
</tr>
<tr>
<td>Fl 1-HS Switch</td>
<td>Fl 1 (Provides an overall response,</td>
</tr>
<tr>
<td></td>
<td>flat within ± 2 dB)</td>
</tr>
<tr>
<td>Monitor Level Control</td>
<td>Variable...(controls the audio</td>
</tr>
<tr>
<td></td>
<td>output at the speaker)</td>
</tr>
<tr>
<td>Calibration ON Switch</td>
<td>Momentarily Depressed...(Provides</td>
</tr>
<tr>
<td></td>
<td>calibration marks at selected</td>
</tr>
<tr>
<td></td>
<td>intervals on the frequency</td>
</tr>
<tr>
<td></td>
<td>scale of the sonagram)</td>
</tr>
<tr>
<td>Calibration Freq.</td>
<td>500 Hz calibration lines</td>
</tr>
<tr>
<td>Select Switch</td>
<td></td>
</tr>
</tbody>
</table>
Frequency Range Switch - 40 to 4000 Hz
Stylus Control Lever - Switchable when making sonagram
Band Selector Switch - Wide
Baseline Adjust Control - Variable..(used to inscribe baseline for amplitude plot)
AGC Switch - OFF
Frequency Scale -
Lin-Log Switch

COMPUTERIZED STATISTICAL EVALUATION:

As previously mentioned each patient examined in this investigation was asked to fill out a history questionnaire and was given a thorough clinical examination that revealed much pertinent data. The data was reduced and organized from a complex maze of facts to an equivalent, simplified program that could be examined and effectively analyzed by computerized analysis. Every patient was given a two digit clinical number (01, 02...21) and was placed in either the normal asymptomatic group or the abnormal symptomatic group. Any variable numerical data such as patients' weight, height, maximum interincisal distance, etc....was indicated as such on a Fortran Computer Coding Form so all related information could be placed on "key punch cards". The following is a chart of related information and method of coding that was included in the computerized statistical analysis of the data:
### Clinical Analysis

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>FIELD (ROW OR COLUMN)</th>
<th>INFORMATION IN FIELD</th>
<th>METHOD OF CODING</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1,2</td>
<td>Patient Number</td>
<td>1-21 normal group</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1'-14' abnormal group</td>
</tr>
<tr>
<td>0</td>
<td>4</td>
<td>Group Designation</td>
<td>1 = Normal Group</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 = Abnormal Group</td>
</tr>
<tr>
<td>1</td>
<td>6,7</td>
<td>Patient's Age</td>
<td>Chronological Age in Years</td>
</tr>
<tr>
<td>2</td>
<td>9,10,11</td>
<td>Patient's Weight</td>
<td>Weight in pounds to nearest pound</td>
</tr>
<tr>
<td>3</td>
<td>13</td>
<td>Patient's Sex</td>
<td>1 = male</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 = female</td>
</tr>
<tr>
<td>4</td>
<td>15,16</td>
<td>Patient's Height</td>
<td>Height in inches to nearest inch</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>Patient's Body Type</td>
<td>1 = Ectomorphic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 = Mesomorphic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3 = Endomorphic</td>
</tr>
<tr>
<td>6</td>
<td>20</td>
<td>Patient's Facial Type</td>
<td>1=Dolichocephalic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2=Mesocephalic</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3=Brachycephalic</td>
</tr>
<tr>
<td>7</td>
<td>22,23</td>
<td>Maximum Interincisal Distance</td>
<td>Measured value in millimeters</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>Occlusion Patient's Right Side</td>
<td>Angle's Class 1,2,3 molar</td>
</tr>
<tr>
<td>9</td>
<td>27</td>
<td>Occlusion Patient's Left Side</td>
<td>Angle's Class 1,2,3 molar</td>
</tr>
<tr>
<td>FIELD VARIABLE</td>
<td>INFORMATION IN FIELD</td>
<td>METHOD OF CODING</td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------</td>
<td>-----------------</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>History of Unilateral or Bilateral Clicking</td>
<td>1 = positive 0 = negative</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>History of Previous Trauma</td>
<td>1 = positive 0 = negative</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>History of Previous Orthodontic Therapy</td>
<td>1 = positive 0 = negative</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Unilateral of Bilateral Cross Bite</td>
<td>1 = positive 0 = negative</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>History of Allergy</td>
<td>1 = positive 0 = negative</td>
<td></td>
</tr>
</tbody>
</table>

*note; One column was skipped between each field on the IBM card.....
### II

#### SONAGRAMIC ANALYSIS

<table>
<thead>
<tr>
<th>FIELD VARIABLE</th>
<th>FIELD INFORMATION IN FIELD</th>
<th>METHOD OF CODING</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Right Joint-Sonagram</td>
<td>Groups 1,2,3,4**</td>
</tr>
<tr>
<td>16</td>
<td>Left Joint-Sonagram</td>
<td>Groups 1,2,3,4</td>
</tr>
</tbody>
</table>

#### Sonagram Characteristics (Frequencies Present)

| 17             | Right Joint-Intensity Sound upon opening-closing movement | Decibel level 1-9 (one level = 6 dB) |
| 18             | Left Joint-Intensity Sound upon opening-closing movement | Decibel level 1-9 (one level = 6 dB) |
| 19             | Right Joint-Intensity Sound upon teeth contacting        | Decibel level 1-9                   |
| 20             | Left Joint-Intensity Sound upon teeth contacting         | Decibel level 1-9                   |

#### Intensity of Sound (Amplitude)

- **Signal Bursts (Number of Units of Sound Energy)**

<p>| 21             | Right Joint Sonagram Signal Bursts upon opening-closing | Range 1-9 0 = 9 or more |
| 22             | Left Joint Sonagram Signal Bursts upon opening-closing  | Range 1-9 0 = 9 or more  |</p>
<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>FIELD (ROW OR COLUMN)</th>
<th>INFORMATION IN FIELD</th>
<th>METHOD OF CODING</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>55</td>
<td>Right Joint Sonagram</td>
<td>Range 1-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Signal Bursts upon</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>teeth contacting</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>57</td>
<td>Left Joint Sonagram</td>
<td>Range 1-9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Signal Bursts upon</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>teeth contacting</td>
<td></td>
</tr>
</tbody>
</table>

**note:** Each patient's sonagram was grouped into one of four groups of which the criteria of will be discussed in the results and findings.
METHODS OF STATISTICAL ANALYSIS:

Where absolute numerical values (continuous data) were recorded, an independent group T-test was utilized. Variables 1, 2, 4, 7 and 21-24 was data of this type. Variables 15 and 16 (right and left TMJ Sonagram Groups) had Chi Square determinations between groups (normal versus pathologic) and between one another (right joints versus left joints) to determine any statistical significance of group distributions. It was assumed that the data from the normal group should show a characteristic distribution pattern and the data of the pathologic group should, if significant, distribute itself differently. This premise was assumed to be valid due to the fact that this was the first study of this nature and one of the purposes of this investigation was to establish a norm sonographic range. Therefore, major emphasis was placed on comparing the pathologic group to the normal group.
CHAPTER IV

RESULTS AND FINDINGS

REPRODUCIBILITY OF RECORDING TECHNIQUE:

It was determined from the sonagrams of a pilot group of 7 patients that the recording technique used in this investigation was reproducible. Each subject tested had sonograms that revealed frequency components that were repeatable from one recording session to the next. For example, if a patient initially showed a sonagram having a preponderance of low frequency components in the first recording session the same frequency components were also present in subsequent sonagrams. The sonographic pattern or graphic picture of these frequencies was in most cases very similar, but it was noted that, as a rule, most opening-closing movements appeared to have slightly different patterns each recording session; and, also different from one opening to the next during the same recording session. The most diagnostic repeatable pattern in every sonagram in this investigation was the picture of the teeth contacting. Teeth contacting showed a high single spike of frequencies ranging from 40 to 4500 Hz (cycles per second) with an intensity of 4 decibel levels (1 dB level - 6 dB or
24 dB total). Therefore, from the forementioned evidence it was assumed that recording technique, if properly executed, is reproducible from one recording session to the next.
RESULTS

INTRODUCTORY COMMENTS:

The results of this investigation can be divided into two main categories. Of primary importance were the findings of the sonagraphic analysis of the right and left temporomandibular joints. In addition, a thorough clinical examination of every subject yeilded much pertinent data. Therefore, the results and conclusions of this investigation will be divided into the following two sections:

2. Sonagraphic Findings.
I. CLINICAL OBSERVATIONS AND FINDINGS

VARIABLE NUMBER INFORMATION IN FIELD AND FINDINGS:

1. **Mean Age:** The mean age of the normal group (Group A) was 25.29 yrs. ± 5.47; whereas, the mean age of the abnormal group (Group B) was slightly greater, 28.26 yrs. ± 11.61. There was no significant difference of the means at the 0.05 level of significance. (See appendix for tables of the T-tests, $X^2$-determinations, and correlation coefficient tests for the conical and sonographic data.)

2. **Mean Weight:** The mean weight for Group A was 148.29 ± 38.30; and, it was 136.29 ± 31.48 for Group B. It is apparent that the mean weight of the normal group is above that of the abnormal group. This was probably due to the proportionately greater number of females and subjects of smaller body stature in the abnormal group.

3. **Sex Distribution:** Group A consisted of 11 males and 10 females; whereas, Group B had 8 females and 6 males (57% ♀) a possible reason for the lower weight and height mean values. Chi Square distribution test showed no significant difference at the 0.05 level.
4. **Mean Height:** The mean height for the normal group was 67.67 in. $\pm$ 3.53; and the mean height for the abnormal group was slightly lower, 65.36 in. $\pm$ 4.65. The T-test showed no significant difference between the two groups.

5. **Body Type Distribution:** Group A and Group B distributed as follows in relation to patient's body type:

<table>
<thead>
<tr>
<th>BODY TYPE</th>
<th>A (normal)</th>
<th>B (abnormal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ectomorph</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td>Mesomorph</td>
<td>13</td>
<td>3</td>
</tr>
<tr>
<td>Endomorph</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>

It was observed that patients of the symptomatic group tended to have an ectomorphic body type; while, those of the normal tended to be mesomorphic. Chi Square determination showed a significant difference in distribution between group A and B.

6. **Facial Type Distribution:** Group A and Group B distributed as follows in relation to facial types:

<table>
<thead>
<tr>
<th>FACIAL TYPE</th>
<th>A (normal)</th>
<th>B (abnormal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dolichocephalic</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Mesocephalic</td>
<td>10</td>
<td>3</td>
</tr>
<tr>
<td>Brachycephalic</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>21</strong></td>
<td><strong>14</strong></td>
</tr>
</tbody>
</table>
Chi Square determination showed a significant difference in group distributions. Subjects in Group A tended toward mesocephalic facial types; while, the dolichocephalic facial type tended to be the most frequent in the symptomatic sample. Therefore, variables 5 and 6 show that the normal group of subjects have a tendency toward mesomorphic and mesocephalic categories; and, the abnormal group tended toward ectomorphism and having dolichocephalic facial type.

7. Maximum Interincisal Distance: The mean for the normal group was 64.19mm (range 41mm to 56mm; S.D. = 3.41). The mean for the abnormal group was 47.79mm (range 37mm to 59mm; S.D. = 7.52). Maximum interincisal distances did not vary significantly from one group to the other. The symptomatic patients had greater range of limits and slightly greater maximum interincisal distances.

8,9. Classification of Occlusion: Right side (variable 8) and left side (variable 9) - The occlusion of the right and left side of every patient was classified according to molar relationship (Angle's Classification). One of the criteria for the normal group was to have
Class I occlusion; therefore, the entire group had a right and left side Class I molar reaction. The abnormal group significantly tended toward Class II.

10. History of Clicking: In the normal group only one patient reported past history of TMJ clicking. The abnormal group significantly had a greater frequency of past and/or present history of clicking. The abnormal group had 9 patients exhibiting TMJ crepitation.

11. History of Trauma: Group A had 4 subjects with history of past traumatic injury to the lower jaw; whereas, Group B had a significantly greater incidence of traumatic injuries. There were 9 subjects in Group B with past history of trauma.

12. History of Orthodontia: None of the subjects of the normal group had any history of past or present orthodontic therapy. Group B had two patients that reported past orthodontic therapy.

13. Crossbite: Subjects of the normal group had no crossbites. The abnormal group had 3 subjects having unilateral crossbite.
14. History of Allergy: In Group A only 2 subjects had history of allergic reactions and Group B had 3 subjects reporting history of allergies.

II. SONAGRAPHIC FINDINGS

15.16. Sonagram Groups - (Right and Left Joints): Sonographic analysis of the right and left temporomandibular joints revealed frequency characteristics that enabled the author to categorize sonagrams into one of four groups. The following are the guidelines or characteristic criteria for grouping sonagrams:

Group I: LOW FREQUENCY CHARACTERISTICS - This group is characterized by a preponderance of lower frequency components in the 40 to 2000 Hz range. The frequency components are very similar during both the opening and closing phases, with the exception of the latter being of slightly shorter duration. Patients tended to open slowly and evenly; and, tended to close more abruptly. The sonographic picture of teeth contacting in this group was a single peak or burst of sound composed of frequency components from 40 to 4500 Hz (Fig.20A).

Group II: COMBINATION LOW AND HIGH FREQUENCY CHARACTERISTICS - This group had characteristics similar to Group I; but, in addition to low frequency components there were some higher frequency components from 2000 Hz to 4500 Hz. The baseline for the amplitude plot was used as the criteria for determination of high frequency components being present. If there were any frequency components during the opening-closing phases above the baseline the sonagram was categorized in Group II (Fig.20B).
FIGURE 20
SONAGRAM GROUPS

Low Frequency Characteristics

GROUP I

GROUP II

Low and High Frequency Characteristics
Group III: STACCATO CHARACTERISTICS - This group is characterized by irregular, abrupt, "staccato-like" bursts of sound energy in the high or low frequency ranges. The most characteristic feature of this group was the irregular short amplitude spikes that were related to crepitus, clicking, or a high noise content on the TMJ recording. Therefore, basis for this group classification was primarily on the appearance of the amplitude pilot and the number of signal bursts per opening-closing movement (Fig.21A).

Group IV: CLEAN GROUP - Relative absence of/or small amounts of sound energy present on the sonagrams. Very few patients fell in this group; but, patients by clinical observation, seemed to be of small stature and had flaccid or frail musculature. The characteristic spike of the teeth contacting was present in this group (Fig.21B).

17. Decibel Level During Opening-Closing Movement - (Right Joint): The mean dB level (1 dB level = 24 decibels) for the opening-closing movement of Group A was 3.76 ± 0.70; whereas, Group B had a mean dB level of 4.00 ± 0.00. As mentioned in the methods, it was necessary to maintain a constant dB level when recording with the tape machine; and, when later transcribing the TMJ sounds onto the recording heads of the sonagraph. The dB levels were controlled by direct observation of the VU meters on the tape machine and sonagraph (Fig.12). This measurement has no direct bearing on the results or findings; but, was included to demonstrate the standardization of all recordings.
FIGURE 21
SONAGRAM GROUPS

A. GROUP III
Staccatto Characteristics - Indicative of Crepitation, Cracking or Clicking Sounds.

B. GROUP IV
Clean Group - Absence of/or Very Few Signals.
Therefore, variables 17, 18, 19, and 20 were designed to statistically show standardization of all sonagrams. There was no significant difference in the groups at the 0.05 level.

18. **Decibel Level During Opening-Closing Movement - (Left Joint):** The mean for Group A was 3.7143 ± 0.7838 and the mean for Group B was 4.00 ± 0.00. Again, there was no significant difference in groups at the 0.05 level.

19. **Decibel Level - Teeth Contacting - (Right Joint):** The mean for Group A was 4.00 and the mean for Group B was also 4.00. There was no significant difference in the readings at the 0.05 level.

20. **Decibel Level - Teeth Contacting - (Left Joint):** The mean decibel level for Group A was 3.9048 ± 0.3008 and the mean for Group B was 4.00. Again, there was no significant difference in the readings at the 0.05 level.

21. **Signal Bursts During Opening-Closing Movement - (Right Joint):** The number of signal bursts in each opening-closing movement was recorded for both the right and left sonagrams. The range of the data was from 0 to 9. Group A had a mean of 3.6667 ± 1.7417 and Group B had a
mean of $5.6427 \pm 1.6919$. There was a significant difference between Group A and Group B at the 0.05 level. The symptomatic group (Group B) had a greater mean number of signal bursts during the opening-closing movement than the normal group. Subjective description of the sonagrams of this group noted the presence of crepitus, clicking, or greater amounts of noise on the recordings.

22. Signal Bursts During Opening-Closing Movement - (Left Joint): Group A had a mean of $3.5238 \pm 1.6315$ signal bursts and Group B had a significantly greater number (0.05 level) with a mean of $5.357 \pm 1.8232$.

23.24. Signal Bursts - Teeth Contacting - (Right and Left Joints) This was the most characteristic reading on all sonagrams and the means and standard deviations are presented in the following chart:

<table>
<thead>
<tr>
<th></th>
<th>MEAN</th>
<th>S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right Joint Sonagram</td>
<td>1.0476</td>
<td>±0.2182</td>
</tr>
<tr>
<td>Left Joint Sonagram</td>
<td>1.0000</td>
<td>±0.0000</td>
</tr>
</tbody>
</table>

There was no significant difference at the 0.05 level in either of the groups.
POPULATION CORRELATION COEFFICIENT - FINDINGS:

There were positive correlations at the 0.05 level of significance between the right and left joints in reference to group designations. If an individual's right sonagram was in Group I then the left would, in the majority of cases, have the same group designation; probably due to identical characteristics of the sonagrams. There were also positive correlations at the 0.05 level between the right and left joints when analyzing number of signal bursts. If the right sonagram had 5 signal bursts; then, the left sonagram would most likely have the same number. Therefore, the majority of right and left sonagrams had identical characteristics and were grouped accordingly.

CHI SQUARE DETERMINATIONS - FINDINGS:

The $x^2$ distribution test was done with variables 3, 5, 6, 10, 11, 14, 15, and 16 between Group A and Group B. The findings were as follows:
<table>
<thead>
<tr>
<th>NO.</th>
<th>DESIGNATION</th>
<th>df</th>
<th>$\chi^2_{(0.05)}$</th>
<th>$\chi^2_{\text{ACTUAL}}$</th>
<th>SIGNIFICANT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Pts. Sex</td>
<td>1</td>
<td>3.841</td>
<td>0.507</td>
<td>---</td>
</tr>
<tr>
<td>5</td>
<td>Pts. Body Type</td>
<td>2</td>
<td>5.991</td>
<td>10.299</td>
<td>***</td>
</tr>
<tr>
<td>6</td>
<td>Pts. Facial Type</td>
<td>2</td>
<td>5.991</td>
<td>9.147</td>
<td>***</td>
</tr>
<tr>
<td>10</td>
<td>Clicking</td>
<td>1</td>
<td>3.841</td>
<td>108.765</td>
<td>***</td>
</tr>
<tr>
<td>11</td>
<td>Trauma</td>
<td>1</td>
<td>3.841</td>
<td>7.924</td>
<td>***</td>
</tr>
<tr>
<td>14</td>
<td>Allergy</td>
<td>1</td>
<td>3.841</td>
<td>2.317</td>
<td>---</td>
</tr>
<tr>
<td>15</td>
<td>Rt. Joint - Group</td>
<td>3</td>
<td>7.815</td>
<td>22.411</td>
<td>***</td>
</tr>
<tr>
<td>16</td>
<td>Lt. Joint - Group</td>
<td>3</td>
<td>7.815</td>
<td>23.728</td>
<td>***</td>
</tr>
</tbody>
</table>

The Chi Square determination showed a significant difference (0.05 level) in Group A and Group B distributions for the following variables:

1. Body Type
2. Facial Type
3. History of Clicking
4. History of Trauma
5. Right Joint - Group distributions
6. Left Joint - Group distributions

The Chi Square determinations showed no significant difference (0.05 level) in Group A and Group B distributions for Allergy.
One of the objectives in designing this experiment was to assure that Group A was composed of non-orthodontically treated, excellent occlusions. Therefore, there would be no clinical significance, in differences in distributions of classification of occlusion, history of orthodontia, or presence of cross-bite. Any individual having evidence of the forementioned would have been immediately eliminated from the normal group. Only variables that could randomly distribute themselves into either the normal or pathologic group were given any clinical significance.
SUMMARY OF IMPORTANT FINDINGS:

1. Patients having symptoms of TMJ dysfunction had a tendency toward ectomorphism and dolichocephalic facial type.

2. There was no significant differences in the means at the 0.05 level for the following:
   a. Age
   b. Weight
   c. Height
   d. Maximum interincisal distances
   e. dB levels during opening-closing phase
   f. dB levels during teeth contacting in centric occlusion

3. There was a significant difference at the 0.05 level in number of signal bursts during the opening-closing phase between the normal and abnormal groups. Group B tended to have more signal bursts or a higher amount of noise in their right and left sonagrams.

4. The most characteristic, repeatable reading in all sonagrams was the picture of teeth contacting. There was no significant difference between groups at the 0.05 level.
INTRODUCTORY COMMENTS:

One of the objectives of this investigation was an attempt to stimulate interest in the diagnostic value of sound in dentistry. Our medical colleagues use sounds produced by the body in the diseased state and compare them to those in health. Audible body sounds that have some diagnostic significance include:

1. Respiratory sounds
2. Cardiac sounds
3. Vascular murmurs
4. Abdominal sounds

Sounds of respiration called "stridors" (Graves and Graves, 1965) are caused by obstruction somewhere between the vocal cords and the main bronchi and; may lead to the diagnosis of tumors, aneurysms, congenital laryngeal stridor, larngitis stidulosa, and many other disorders.

Some body sounds are not readily discernible without the use of special instruments such as the stethoscope.

These sounds are:

1. Intracranial sounds
2. Heart and lung sounds
3. Vascular sounds, e.g. aneurysms
4. Muscular sounds, e.g. uterine contractions
5. Abdominal sounds, e.g. gut; foetal
6. Joint sounds, of great importance to this investigation

Just as cephalometric analysis opened the eyes of orthodontists to new facets of diagnosis and treatment planning, an interest in dental sound warrants analytical investigation to its significance as a diagnostic tool.

The Cardiologist demonstrates analytical use of sound as a diagnostic tool by observation of the following qualities in the heart sounds:

1. Normal first, second, third and fourth sounds
2. Normal and abnormal splitting of sounds
3. Murmurs heard in systole
4. Murmurs heard in diastole
5. Extracardiac sounds such as in pericardial friction rub

Mention of the above in the discussion is an attempt to draw a parallel between our medical colleague's use of sound as a diagnostic tool, and this investigation of the temporomandibular joints using sound as a diagnostic medium.

SUBJECTIVE ANALYSIS OF JOINT SOUNDS:

The following is the author's interpretation of normal and abnormal temporomandibular joint sounds as viewed subjectively:
NORMAL JOINT SOUNDS.....Characteristics

Opening Phase: Smooth, rhythmic, "HISSSSSS-sound" characterized by a gradual increase in volume or intensity until the height of the opening movement is completed (Max. Interincisal Dist.)

Closing Phase: Smooth, rhythmic, "HISSSSSS-sound" with the same or very similar characteristics as above, except of slightly shorter duration.

Teeth Contacting: A sharp, crisp, abrupt, emphatic sound of even shorter duration than either the opening or closing phase.

ABNORMAL JOINT SOUNDS.....Characteristics

Opening Phase: Irregular, crackling, popping sounds characterized by sporadic increases and decreases in volume or intensity until the end of the opening phase.

Closing Phase: Most of the time identical and of shorter duration than the opening phase.

Teeth Contacting: Identical to the normal group of patients.
OBJECTIVE ANALYSIS OF JOINT SOUNDS:

Joint sounds when analyzed by the sonagraph revealed data that when reduced could be placed into four characteristic groupings. As Emmering (1967) classified the condyle-eminential complex, this investigation established four basic "TMJ sound prints" relationships. Whether there are any correlations with Emmering's findings should be further investigated by combining laminography with the electronic auscultatory technique.

The four classifications of TMJ sounds include:

Group I: A predominance of low frequency components (40-2000 Hz).
Group II: Combination of low and high frequency components (40-2000 and 40-4500 Hz).
Group III: Staccato Characteristics...many short, irregular signal bursts with low and high frequency components (40-4500 Hz).
Group IV: Clean group...void of/or very little signal components (40-500 Hz).

It was not possible to give objective reasoning why the subjects seemed to distribute themselves into four categories; however, the author wishes to speculate on a few possible reasons for the differences in sonagrams.

Sound can be modified from one individual to the next by resonance in cavities such as the air sinuses of the skull.
Sound waves can also be modified by reflection or absorption of some of its components. Therefore, different degrees of bone density; morphological and anatomical variation; different thickness of muscular, integumental, and connective tissue coverings will in the author's opinion, modify the sound waves emanated by the joints.

Almost all sound will ultimately cause vibration which will manifest itself as alternate movements of compression and rarefaction in adjacent molecules or particles. Thus, sound as a form of energy is related to vibration of particles. Graves and Graves (1965) said: "The frequency at which any object vibrates is always the same for that object and is related to various of its properties such as length.". The frequency of a vibrating object is the number of complete movements per second and its maximum excursion is the amplitude (Fig.21).

Therefore, bone as a conductor of sound can be analogous to a tuning fork. Each individual's bony structure by variations in length, width, densities, resonance, etc. is a different "physiologic tuning fork". Thus, each bone will vibrate at a slightly different rate characteristic for that individual. The author's contention is that
anatomical and morphological variance is a possible explanation for the difference in sonagrams from one individual to the next.

RELATION OF TMJ DYSFUNCTION TO ELECTROMYOGRAPHIC INVESTIGATION:

Electromyographic studies have many variables and disadvantages. Some of these variables are:

1. Difficulty in standardization of electrode placement.
2. Presence of electrical background interferences or the difficulty in complete elimination of the aforementioned.
3. Individual variation.
4. Time of day subjects are recorded.
5. Variation in skin conduction and skin resistance.
7. Effects of postural changes on readings.
8. Difficulty in exact calibration of electromyograph between recording sessions.

The variables in this type of study would include the difficulty of determining exact electrode placement over the muscles being tested. Due to anatomic and morphologic variations from one individual to another prevents exact, reproducible, electrode placement from one test period to the next; or, from one subject to the next.

MICROPHONE PLACEMENT VERSUS EMG ELECTRODE PLACEMENT:

The present investigation admittedly has some variables and disadvantages; however, microphone placement did not appear to be one of them. Since bone is an excellent
conductor of sound waves it would have been possible to have made recordings with the microphones placed on the forehead (Brennan and Millsap, 1959); inferior border of the mandible (Conant, 1962); or in the occipital region. Variation in microphone placement caused differences in amount or quantity of signals picked up and there was evidence of cross-over or summation of signals of the right and left joints.

Since this investigation was interested in studying right and left joints as separate entities, the cheek bones (os zygomaticus; Ekensten, 1952) was the site of choice for microphone placement. Admittedly there was a degree of cross-over, and summation of sound signals from the right and left joints; but, due to differences in intensities (dB levels) this variable was compensated for. In essence, only the higher dB levels of each sonagram were considered in the classification of sonagrams.

Therefore, in the author's opinion, microphone placement is not necessarily a disadvantage or shortcoming of this investigation. At least, there is less error in the assumption that microphone location is repeatable from
one subject to the next, than electrode placement in EMG investigations is exact from one subject to the next.

**VARIABLES OR SHORTCOMINGS OF SONAGRAPHIC ANALYSIS OF THE TMJ:**

An effort to objectively analyze TMJ sounds was carried out; but, as in any investigation there are always variables and shortcomings. In the author's opinion, there were the following possible variables:

1. Cross-over or summation of signals from the right joints to the left joints.
2. Time of day recordings were made.
3. Exact maintenance of head position during recordings.
4. Difficulty of standardization of the right and left channels of the tape recorder.
5. Difficulty of standardization of the right and left channels of the sonagraph.
6. Difficulty of matching impedance of the crystal microphones to the recording instrument.
7. Difficulty of elimination of all background interferences.
8. Difference in rates and patterns of opening-closing movements from one patient to the next.
10. Subjectivity in clinical examination of patients.
11. A cross-sectional investigation as opposed to a longitudinal investigation.
Enumeration of all the possible variables in this investigation led the author to the following means of elimination:

**Cross-Over:** Cross-over or summation of signals was compensated for by carefully analyzing only those frequencies in the higher decibel levels. It was assumed that signals of the greatest intensity could have only come from the ipsilateral joint.

**Time of Day:** The majority of recordings were made between the hours of 9A.M. and 4P.M. during clinical hours only. Patients did not, for the most part, seem fatigued or have their physiologic homeostasis upset because of the time of day they were tested.

**Head Position:** Exact maintenance of head position during recordings was accomplished by standardized patient instruction (see methods). Every patient was instructed to look straight ahead and the operator assured that the patient's Frankfort horizontal was parallel to the floor. It was assumed that variance of head position would affect subsequent recordings as described by Robinson (1966) and Carter (1959) in relation to EMG studies.
Tape Recorder Standardization: By utilization of the automatic record level switch; use of the balance control; and direct observation of the right and left VU meters on the tape machine it was not difficult to equalize the two channels during recording sessions. Before sonagraphic analysis of any portion of the tapes both channels could be exactly equalized by adjusting the input and record-level switches, and observing a constant reading on the VU meters. All recordings were analyzed with the VU meters reading at 20 (Fig.12). Thus, it was possible to equalize any recording prior to sonagraphic analysis. Standardization of the electronic equipment was a minor problem in the investigation.

Sonagraph Standardization: Anyone desiring to repeat or augment this investigation is directed to the settings used to standardize the sonagraph. After several test sonagrams it was found that these settings gave the operator the best quality and best standardized sonograms from one testing period to the next.

Impedance Matching: According to Graves and Graves (1968) impedance is... "the measure of resistance to the
passage of alternating current through any piece of electronic equipment such as a recorder, a microphone or a length of cable". For the best results it is important that the input impedance of the tape recorder matches the output impedance of the microphones. Zenith Laboratories, Chicago, Illinois, fabricated the microphones used in this investigation and assured the operator that the impedances were adequately matched.

**Background Interferences:** The purpose of two pilot studies was to determine the best recording technique free of extraneous background interferences. Anyone repeating the procedure is urged to use bone conduction microphones as opposed to air conduction phones (Fig. 3 and Fig. 4). It is of paramount importance that the patient's head position be maintained during the recording session and there is no sudden movement causing the microphones to be jarred. Jarring of the microphones will cause a background noise that may be mistaken for the teeth contacting.

**Opening - Closing Pattern:** There was a variance of the opening-closing movement from one patient to the next. Some individuals opened slowly and evenly; while, others
opened with an abrupt, jerking motion. Thus, the sonagrams differed in respect to patterns or time intervals of the opening versus closing phases. Even though the sonagram patterns differed from one individual to the next, the frequency and amplitude values were constant and reproducible from one opening-closing movement to the next; or, from one recording session to the next.

Sonagram Groups: When analyzing the sonagrams of the normal and abnormal groups each tracing was randomly placed one next to the other, on a large table. A panel of three electronic experts (J. Sinclair, B.S., M.S., Ph.D.; W. Ely, B.S., M.S.; S. Larson, B.S., M.S.: Zenith Radio Corporation, Hearing Aid Division, Chicago, Illinois.) examined the TMJ Sonagrams and discovered characteristics that placed them into one of four groups. Subjectivity of the sonagram analysis was eliminated as the panel did not know whether subjects were part of the normal group or part of the abnormal group. Sonagrams were objectively examined for frequency and amplitude components. The panel later consulted with the author and thoroughly discussed the criteria that separated one group from the other. Therefore,
due to the guidelines set up by the panel of experts, sonagrams of the temporomandibular joint can be classified into one of four groups.

Clinical Examination: An effort to eliminate subjectivity in giving patients a clinical exam was accomplished by closely following a format (Fig. 2), the clinical examination form. This method of examination was a shortened version of the clinical exam form used by Shore (1959). Shore's thoroughness and objectivity in giving a clinical examination enabled the author to evaluate many aspects of the patient's physical and dental health.

Cross Sectional Data: One of the disadvantages of many investigations is that results, findings, and conclusions are based on a cross-section of subjects rather than collecting data from a longitudinal subject group. The only longitudinal part of this investigation involved 6 clinical patients that were tested and retested with an effort to establish reproductability of recording and sonographic analysis technique. It was concluded that the methodology was repeatable; and, that a cross-sectional group of subjects could be effectively used to establish a "norm sonographic range".
COMPARISON OF PREVIOUS INVESTIGATION WITH THE PRESENT STUDY:

Early studies of TMJ Pathosis were numerous; but, the majority of the works employed subjective description especially when referring to joint sounds. From Cooper (1823) giving the first description of TMJ dysfunction to the works of Annodale (1887), Pringle (1918), Axhausen (1930), Costen (1934), and Foged (1940) all had in common subjectivity in their description. The present investigation attempted to narrow subjective description; and, in the author's opinion, could be compared to the works of Ekensten (1952), Brenman and Millsap (1959), Conant (1962), and Watt (1963, 1965, 1966).

Ekensten (1952) supported the observation that majority of TMJ diagnostic techniques do not give an objective picture. Ekensten and the author both agree that x-ray techniques are not 100% reliable and can not explain what happens during the dynamics of functional movements of opening and closing the mandible. Microphone placement in Ekensten's study was over the os zygomaticus or os temporale. This investigation utilized the os zygomaticus location as superior quality recordings were
more readily obtainable, and were relatively free of background interferences. Ekensten used oscilloscope analysis of sound signals; whereas, this investigation used the sonagraph. The oscilloscope traces in the first study were photographed and logged for future reference. This investigation employed paper tracings of the sound components of TMJ sounds. The advantages of the sonagraph over the oscilloscope "phonograms" in sound analysis were apparent because of the following:

1. Sonagrams give one a picture of amplitude and frequency components; whereas, the oscilloscope is better used for amplitude plots only.

2. Sonagraphic technique is more exact in analysis of segments of sound. The oscilloscope-photographic technique can be cumbersome and of less accuracy in analyzing a specific segment of a TMJ recording.

3. Sonagraphic technique has the advantage of separation of the amplitude components from the frequency components. It was previously noted that amplitude plot was separated from the sonagraphic trace and included on the upper 1/3 of the sonagram.

4. Sonagrams are a three-dimensional picture of sound signals; whereas, the oscilloscope gives one a two dimensional analysis. Sonagrams give a visual tracing of frequency amplitude and decibel levels as a function of time.

5. It is possible to inscribe a calibration tone signal of 50, 5000, or 1000 Hz on a sonagram. This procedure is difficult to do accurately with the oscilloscope methods.
6. Bilateral or stereophonic analysis of joint sounds is easier and more accurate using the sonagraph.

Ekensten analyzed a normal group of 35 patients and stated that..."a physiological joint, having no anomalies, does not register any acoustic phenomena". The present study supported this observation as there was no significant incidence at the .05 level of TMJ clicking or crepitation in the normal sample of 21 subjects. Subjects having TMJ difficulties in Ekensten's investigation showed..."that the anomaly has a definite characteristic which is revealed by the phonogram". Ekensten felt that large amplitude spikes were indicative of subluxations. The present study did not speculate on the causes of specific wave forms; but, it was found that the symptomatic group of 14 subjects significantly distributed themselves in the Staccato Group sonagrams (Group III). It was previously mentioned that this group had a preponderance of frequent, short, crisp signal bursts analogous to the crackling or popping of a piece of cellophane. Therefore, the Staccato Group was associated with TMJ crepitation.

Brennan and Millsap (1959) investigated the sounds of
the teeth coming together using a oscilloscope photographic technique. The authors called their visual displays "occlusograms". Microphone placement in their study was on the frontal bone (forehead). An interesting finding was a significant difference in recordings when a subject's body position was varied. Therefore, each subject was oriented with a device developed by Dr. C. Jerge. This device paralleled the ala tragus line to the shoulders. Recordings in their investigation were made with the patient sitting erect and with the ala tragus line parallel to the floor. Brenman and Millsap found differences in occlusograms between normal patients and patients exhibiting known occlusal discrepancies. The present study did not support this observation. The most characteristic pattern on the sonagram was the picture of teeth contacting. There was little or no variation from one patient to the next. This observation could possibly be attributed to the microphone placement or the differences in technique of oscilloscope when compared to sonarthrography. "Sonarthrography" is the author's coined terminology for the sonagraphic analysis of temporomandibular joint arthrosis.
Conant (1962) investigated TMJ sounds in relation to masticatory force distribution. Microphone placement in Conant's study was against the inferior border of the mandible and a calibration tone of 1000 cycles/second was introduced into his recordings. This was done by placing a signal generator in the forehead of each subject giving the investigator a 1000 cycle/second sound marker. In the author's opinion Conant's methodology was not as precise and of greater difficulty than the sonagraphic methodology.

Conant used a band-pass filter that eliminated sounds not in the 1000 cycle/second range. He also utilized the Sanborn Model 150-400 recorder that gave him paper tracings of the sound components. The present investigation not only analyzed sound in the 1000 Hz frequency, but had the versatility of sound analysis in the 40 to 16,000 Hz range.

Watt (1962, 1964) objectively studied TMJ sounds using an intraorbital position for his microphones. Watt using an oscilloscope photographic technique observed that his traces were reproducible from one recording session to the next. The present study supported this observation as
sonagrams were reproducible for the same subjects up to a 125 day time lapse. Watt (1966) in a study that followed utilized a Ferrograph recorder that gave him paper traces. He called these tracings arthrosonic and occlusonic traces. The limitation of Watt's investigation was 300 to 3000 cycles/second, but the author gave a good objective description of temporomandibular joint sounds.

Therefore, only the forementioned four studies attempted to objectively describe temporomandibular joint sounds and now hopefully the present study can be added to these objective approaches.

**CLINICAL APPLICATIONS OF SONAGRAPHIC ANALYSIS:**

Adverse effects of some orthodontic prosthodontic, oral surgical or operative dental procedures may be the etiological factor or help aggravate existing temporomandibular pathosis. Any pathologic force transmitted through the mandibular joints may cause distilization and possible subluxation of the condyles which if prolonged may have adverse effects on the connective tissues of the joints. This was shown to be true by Ramfjord and Hiniker (1966) and Moffett (1972). Animal studies that involved the
Histologic examination of TMJ's subjected to adverse forces. Hilgers (1972) suggested that the collagen fibers, as well as, the muscular elements that make up the capsular and ligamentous components of the joints may be overstretched and cause a denaturing or breaking down of collagen bonding. This effect may then manifest itself in production of antigenic substances in the capsular area and the subject becomes hypersensitive to his own tissues (autoimmune response). This process leads to further pathological breakdown and depending upon the patient's individual resistance to stress (Selye, 1956) and healing mechanisms the joint's connective tissues may repair at a stretched length. This stretching effect may lead to the so-called "hypermobile joint" as described by Freese and Schemann (1962), as well as, the possibility of joint clicking due to torn connective tissues. Sicher (1955) supports this observation in his observation, an altered disc-condyle relationship will manifest itself by clicking. It should be noted that adverse effects of alteration of vertical dimension by prosthetic devices; premature occlusal contacts by improper operative procedure; stretched capsular tissues
due to oral surgical procedure; or altered occlusion due to orthodontic therapy may have an immediately apparent effect on human subjects, or may remain dormant until later in life when TMJ arthrosis is so prevalent (Shore, 1959). Further study using sonographic analysis of the TMJ may diagnostically identify a dormant joint that is predisposed for future pathological breakdown.
SUMMARY AND CONCLUSIONS

One of the goals of this investigation was to measurably narrow subjectivity in the analysis of TMJ sounds. A quantitative and qualitative evaluation of joint sounds was performed with an audio-frequency spectrum analyzer, the Sonagraph. A group of 21 caucasian subjects having clinically excellent occlusions (Angle's Class I) were subjected to electronic auscultation of their right and left joints. The sounds elicited by their joints were recorded and stored on cassette tapes which were later analyzed by the Sonagraph. The Sonagraph is capable of giving the operator an audio-spectral analysis of complex sound waves, breaking down sound waves into each frequency and amplitude component; as well as, revealing the decibel level of each as a function of time. Every TMJ recording was analyzed in the frequency range of 40 to 4500 Hz which enabled the operator to scan a 4.8 second time interval of opening-closing movements. Thus, it was possible to compare, at least 2 or 3 opening-closing movements for each subject's right and left temporomandibular joint. The 4.8 second recording was electronically marked with a
known calibration tone (500 Hz) so it was possible to view sound components of an opening-closing movement in relation to a calibrated frequency scale. From this group, a "norm sonagraphic range" was determined with the help of a panel of electronic engineers. (Zenith Corporation, Hearing Aid Division, Chicago, Ill.) The panel, after examining the sonagrams of the normal group, set up guidelines or specific characteristics that enabled the operator to group each subject tested into one of four sonagram categories. The "norm sonagraphic range" briefly consisted of the following:

GROUP I: Sonagrams characterized by preponderance of low frequency components (40-2000 Hz).

GROUP II: Sonagrams characterized by combination of low and high frequency components (40-2000 Hz and 40-4000 Hz).

GROUP III: Staccato Group - Irregular bursts of sound correlated with crepitus.

GROUP IV: Clean Group - Absence of most frequency components.

The four categories were assumed to be the hypothetical normal distribution of clinically excellent occlusions free of any joint pathosis. Another group of
14 caucasian subjects having history of past and present TMJ dysfunction were analyzed by the same methodology and statistically compared to the first group. The following are the conclusions of this investigation:

1. Abnormal TMJ sounds such as clicking, snapping, popping, or crepitus appear to have some diagnostic significance.

2. A standardized approach free of most variables was devised to objectively analyze sounds elicited by the right and left temporomandibular joints.

3. This investigation established a "norm sonagraph range" that categorized TMJ sounds into one of four groups by the quality and quantity of the frequency and amplitude components.

4. Subjects of the normal group significantly had sonagrams characterized by a smooth burst of sound of long duration in the range of 40 to 4500 Hz. Normal patients generally distributed themselves in either the low frequency group or the combination of high and low frequency group.

5. Subjects of the abnormal group significantly had sonagrams characterized by coarse, irregular, crisp, abrupt, emphatic bursts of sound of shorter duration throughout the opening-closing movement. Symptomatic patients generally distributed themselves in the Staccato Group (Group III).

6. The majority of right and left TMJ's had similar sonagrams; however, there were slight differences in right and left sonagrams. Therefore, each joint can be viewed as a separate entity.
7. No two opening and closing patterns of the same individual were identical. Right and left joints did not significantly differ, but it was observed that there is the possibility for variation in quality of sound from one to the other.

8. The most characteristic pattern on the sonogram was the picture of teeth contacting.

9. Sonagrams of the temporomandibular joints are reproducible from one recording session to the next as evidenced by reappearance of specific frequency components; therefore, it can be concluded that most individuals have a reproducible TMJ sound print.

10. Patients of the pathologic group having symptomatic TMJ dysfunction had a tendency to have ectomorphic and dolichocephalic body and facial types.

It has been often said "A picture is worth a thousand words", therefore, the illustration on the following page graphically summarizes this research effort:
ELECTRONIC AUSCULTATION

and

SONAGRAPHIC AUDIO-SPECTRAL ANALYSIS

of the TEMPOROMANDIBULAR JOINT
SOUND REPRESENTED AS A SINE WAVE

A = Amplitude - Intensity
B = Base Line - Time Scale in seconds
C = One Complete Cycle
X = at each point X the object is momentarily at rest

Frequency = No. of cycles/sec. (Hz)
### CLINICAL AND SONAGRAPHIC DATA CODING DESIGNATION

#### LEGEND

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<td>E</td>
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| F        | Patient's Body Type          | 1 = Ectomorph  
          |                | 2 = Mesomorph  
          |                | 3 = Endomorph  |
| G        | Patient's Facial Type        | 1=Dolichocephalic  
          |                | 2=Mesochphalic  
          |                | 3=Brachycephalic|
| H        | Maximum Interincisal Distance| Millimeters    |
| I        | Occlusion - Right Side       | Class 1, 2, 3  |
| J        | Occlusion - Left Side        | Class 1, 2, 3  |
| K        | History of Clicking          | 1 = Yes 0 = No |
| L        | History of Trauma            | 1 = Yes 0 = No |
| M        | History of Orthodontia       | 1 = Yes 0 = No |
| N        | Cross-bite                   | 1 = Yes 0 = No |
| O        | History of Allergy           | 1 = Yes 0 = No |
LEGEND CONTINUED

SONOGRAPHIC DATA

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### NORMAL GROUP

#### CLINICAL AND SONOGRAPHIC DATA

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| 02| 31 | 165| M  | 69 | 2  | 2  | 47 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 3  | 3  | 3  | 3  | 4  | 4  | 4  | 4  | 5  | 4  | 1  | 1 |
| 03| 19 | 107| F  | 62 | 1  | 2  | 43 | 1  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 4  | 4  | 1  | 1  | 4  | 4  | 0  | 0  | 1  | 1  |
| 04| 26 | 157| M  | 68 | 2  | 1  | 56 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 2  | 2  | 4  | 4  | 4  | 4  | 4  | 3  | 3  | 1  | 1 |
| 05| 20 | 094| F  | 63 | 1  | 1  | 46 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 4  | 4  | 1  | 1  | 4  | 4  | 4  | 4  | 3  | 3  | 1  | 1 |
| 06| 24 | 203| M  | 73 | 2  | 2  | 48 | 1  | 1  | 0  | 1  | 0  | 0  | 0  | 0  | 1  | 1  | 4  | 4  | 4  | 4  | 4  | 2  | 4  | 1  | 1 |
| 07| 18 | 110| F  | 66 | 1  | 1  | 44 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 4  | 4  | 4  | 4  | 3  | 3  | 3  | 1  | 1 |
| 08| 18 | 110| F  | 66 | 1  | 1  | 44 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 4  | 4  | 4  | 4  | 3  | 3  | 3  | 1  | 1 |
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| 12| 28 | 165| M  | 69 | 2  | 2  | 48 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 2  | 4  | 4  | 4  | 4  | 3  | 3  | 1  | 1  |
| 13| 26 | 118| F  | 64 | 2  | 2  | 42 | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 2  | 2  | 4  | 4  | 4  | 4  | 2  | 2  | 1  | 1  |
| 14| 19 | 118| F  | 63 | 1  | 1  | 49 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 2  | 4  | 4  | 4  | 4  | 4  | 3  | 3  | 1  |
| 15| 27 | 165| M  | 74 | 2  | 1  | 48 | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 2  | 4  | 4  | 4  | 4  | 6  | 5  | 1  | 1  |
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ABNORMAL GROUP
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TABLE A

**BMDO3D - CORRELATION WITH ITEM DELETION**

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<td>1</td>
</tr>
</tbody>
</table>

**VARIABLE DESIGNATION**

1. Right Joint - group designation
2. Left Joint - group designation
3. Right Joint - no. of signal bursts
4. Left Joint - no. of signal bursts

df = 20     p = 0.423    \( \alpha = 0.05 \)
### TABLE B

**BMD03D - CORRELATION WITH ITEM DELETION**

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>NUMBER OF ITEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<td>14</td>
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<td>2</td>
<td>1.3571</td>
<td>0.6333</td>
<td>14</td>
</tr>
<tr>
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<tr>
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**CORRELATION MATRIX**

SAMPLE SIZES IN PARENTHESES

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<th>VARIABLE NO.</th>
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<th>3</th>
<th>4</th>
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<td>1.0000</td>
<td>0.91225</td>
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<tr>
<td>4</td>
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<td>0.91225</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

**VARIABLE DESIGNATION**

1 | Right Joint - group designation
2 | Left Joint - group designation
3 | Right Joint - no. of signal bursts
4 | Left Joint - no. of signal bursts

$df = 13 \quad p = 0.514 \quad \alpha = 0.05$
TABLE C
CORRELATION MATRIX
SAMPLE SIZES IN PARENTHESES

<table>
<thead>
<tr>
<th>VARIABLE</th>
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<th>STANDARD DEVIATION</th>
<th>NUMBER OF ITEMS</th>
</tr>
</thead>
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EMD03D - CORRELATION WITH ITEM DELETION

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VARIABLE DESIGNATION

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<th>DESIGNATION</th>
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<tr>
<td>2</td>
<td>Left Joint - group designation</td>
</tr>
<tr>
<td>3</td>
<td>Right Joint - no. of signal bursts</td>
</tr>
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<td>4</td>
<td>Left Joint - no. of signal bursts</td>
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</table>

df = 34  p = 0.381  \( \alpha' = 0.05 \)
### Continuous Data

#### PATIENT'S AGE AND WEIGHT

**T-TEST OF MEANS BETWEEN TWO GROUPS**

<table>
<thead>
<tr>
<th>VAR GROUP</th>
<th>NUMBER OF OBS</th>
<th>SUM JF VARIABLE</th>
<th>SUM OF SQUARED VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>DIFF OF MEANS STANDARD ERROR</th>
<th>T</th>
</tr>
</thead>
<tbody>
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#### PATIENT'S HEIGHT

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<th>SUM JF VARIABLE</th>
<th>SUM OF SQUARED VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>DIFF OF MEANS STANDARD ERROR</th>
<th>T</th>
</tr>
</thead>
<tbody>
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#### MAXIMUM INTERINCISAL DISTANCE

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<th>SUM OF SQUARED VARIABLE</th>
<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>DIFF OF MEANS STANDARD ERROR</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
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### TABLE D

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<th>MEAN</th>
<th>STANDARD DEVIATION</th>
<th>DIFF OF MEANS STANDARD ERROR</th>
<th>T</th>
</tr>
</thead>
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Mitchell, D.: Personal Communication. March, 1972. (Professor and Chairman, Department of Orthodontics, Emory University, Atlanta, Georgia.)


Walker, W. E.: Prosthetic Dentistry: The Glenoid Fossa:
The Movements of the Mandible: The Cusps of the Teeth.

Watt, D. M.: Preliminary Report on the Auscultation of
the Masticatory Mechanism. D. Pract., and D. Rec.,

: Report on a Method of Direct Occlusal Analysis,

: Gnathosonics - A Study of Sounds Produced by the

: Clinical Applications of Gnathosonics. J. Pros.
The thesis submitted by Dr. Paul L. Ouellette has been read and approved by three members of the Oral Biology Department, Loyola University School of Dentistry, Chicago, Illinois.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

5/17/72

DATE

SIGNATURE OF ADVISER