RECORDING TECHNIQUES AND ANALYSIS OF THE ARTICULAR CRACK

A Critical Review Of The Literature

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Abstract:
Objective: To review the available literature pertaining to the recording and analysis of the joint crack/cavitation sound produced as a result of spinal manipulative therapy. A critical appraisal of the recording and analysis techniques is presented.

Data Source: A broad based search of the English language literature was conducted utilising the databases Medline (1966-1996) and Chirolars (1800-1996), using the key words cavitation, noise, sound, audible release, crack/s/ing, vibration, sound recording, acoustic recording and accelerometers, coupled with the terms facet joint, spinal joint and apophyseal joint and chiropractic, osteopathic and spinal manipulation. A manual search was also conducted of non-indexed journals and text books relating to manual therapy of the library at RMIT University, Bundoora, Victoria.

Results: There appears to be a paucity of this research relating to spinal manipulative therapy. Research to date has focused on recording the joint crack sounds via microphones or piezoelectric accelerometers both of which appear to have limited applications.

Conclusion: Some worthwhile information may be gained by conducting further research into the joint crack phenomenon, particularly with respect to spectral analysis. However, before this research is undertaken a more reliable and accurate means of capturing and processing the joint crack signal needs to be established.

Key Indexing Terms: Joint crack, cavitation, noise, sound, audible release, vibration, recording, spinal manipulative therapy.

INTRODUCTION

The interpretation of joint sounds for diagnostic purposes probably dates back to prior 1848 and is mentioned in Laennec's treatise on mediate auscultation(1). With the development of the stethoscope these sounds were able to be amplified to an audible level but it was not until the age of the personal computer and modern advancements in the field of electronics that any worthwhile research was undertaken.

Unlike the medical and dental professions, the chiropractic and osteopathic professions have contributed very little to the understanding and the significance of this phenomenon. Since the advent of the personal computer the two former professions have produced some promising research in this field and have developed recording and analysis systems which have the capability of not only identifying the source of the joint sound but also the cause(2,3).

The articular crack associated with spinal manipulative therapy (SMT) is familiar to most practitioners of that discipline and is regarded by some to be a sign of a successful manipulation and the difference between manipulation and mobilisation(4). Regardless of its therapeutic benefits, from clinical experience, many patients and practitioners alike feel less than satisfied if a manipulative procedure fails to elicit this articular cracking sound(5).

The mechanism responsible for this sound, at least in the finger joints, is thought to be due to the cavitation of an intra-articular gas bubble(6). However, although it would be logical to assume that the same process is responsible for the cracking sound produced by SMT, to date no research has been conducted to support this assumption.

METHODS

A broad based search of the English language literature was conducted utilising the databases Medline (1966-1996) and Chirolars (1800-1996), using the key words cavitation, noise, sound, audible release, crack/s/ing, vibration, sound recording, acoustic recording and accelerometers, coupled with the terms facet joint, spinal joint and apophyseal joint and chiropractic, osteopathic and spinal manipulation. A manual search was also conducted of non-indexed journals and text books relating to manual therapy of the library at RMIT University, Bundoora, Victoria.

RESULTS

A total of 19 articles were found, but of these only 8 papers possessed a sufficient description of the methodology to conduct any worthwhile review (7-14). The remaining 11 articles were either reviews, rewrites of original research or utilising the original research to discuss other aspects of the SMT process, or conference proceedings(15-23). In all the relevant articles either microphones,

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responding to changes in sound pressure levels, or piezoelectric accelerometers, responding to mechanical vibrations, were used as transducers to capture the joint crack signal. Recording of the signal was achieved by using analogue or digital tape or ultraviolet recording devices. Analysis of the captured signal was performed either visually, mathematically or by computer aided sound spectrum analysis software.

Microphone Recording:
What appears to be the first recording of the joint crack associated with SMT is mentioned by Sandoz(15) and relates to what is thought to be a phonocardiographic recording by Wolff(16) in 1967. However, no mention is made of the actual recording process or the spinal region manipulated, except that the illustration of the recorded noise is accompanied by a hand written notation of "C3/4". Sandoz states that according to Wolff , "the best results are obtained when the higher frequencies are eliminated, as the disturbing effect of adventitious noises occurs in the higher frequencies". Further, "the only reliable information obtained from such graphs pertains to the duration of the cracks: 4-6/100 sec". Lewit in 1978 (17). Briefly mentions the articular crack associated with SMT and states "the click as a sign of successful manipulation, is a typical articular phenomenon, as is the restoration of joint play". Several illustrations accompany this statement and depict the articular "click" of normal and blocked joints, and blocked joints after manipulation, which were recorded on phonographic tape. Unfortunately no mention is made of the precise method of recording or what joint was manipulated.

Méal and Scott(7), 10 years after conducting their original research(24), published their findings with respect to the analysis of the joint crack. This research was originally designed to analyse joint tension pre and post joint cracking of the metacarpophalangeal (MCP) joints but apparently the authors also recorded joint crack signals during manipulation of the cervical spine.

No mention is made of the equipment set-up for the recording of the cervical joint cracks but for the MCP joints a sound proof room was used. The cracks were captured using a microphone, of unknown quality and specifications, attached to a sound level meter, which was in turn connected to a 1 kHz Octave Band Filter. The signal was then processed through a Full Wave Rectifier before being recorded on an Ultraviolet Recorder.

After analysis of both the MCP and cervical joint crack signals the authors concluded that as both wave forms were exactly the same, the cracking sound produced by cervical SMT originated from the apophyseal joints. They found the wave patterns for all signals to be very consistent in that they all possessed a two peak wave form with the duration of the sound being between 0.025 and 0.075 seconds. The joints also seemed to crack more easily with a decrease in atmospheric pressure, needing less tension and making less noise.

Méal and Scott(7), by failing to describe the recording methods for the cervical joint cracks, the SMT technique or the type of microphone used, leave open to question the validity of their study on cervical joint crack sounds. Also, the use of a 1 kHz filter may not provide enough band width for full spectral analysis. It would also be logical to assume that as the cervical apophyseal joints are different in shape and size to those of the MCP each would produce a different signal. The spectral characteristics would also be different, particularly in the higher frequency range, due to the damping effect of the different overlying soft tissue thickness of the two joints. Further, it would be impossible to eliminate all extraneous noise when applying SMT due the physical nature of the SMT procedure, even in a sound proof room, which may then reflect in the accuracy of the recorded signal.

In 1986 two dentists, Woods and West(8), published their research designed to compare temporomandibular joint sounds with the sounds produced by manipulation of other joints, including the zygapophyseal joints of the cervical, thoracic and lumbar spines. The recording technique employed was via an Electret microphone fitted to a modified stethoscope bell which in turn was connected to a professional quality cassette tape recorder. The captured signals were then transferred to an electronic transient recorder and displayed on an oscilloscope and finally plotted on a chart recorder for frequency analysis by one-way analysis of variance using a statistical calculator.

This paper was based on an original research thesis submitted by M. Woods(25). In his research the author stated that a preliminary study investigated frequency analysis utilising Fast Fourier Transformation but that no additional useful data was obtained over and above that obtained from frequency analysis of the wave patterns, using controlled plotting of the chart recorder with reference to the time scale. According to Woods and West(8) the mean frequencies for the manipulated joints were, cervical spine 75.57 Hz +/- 8.69, thoracic spine 66.84 Hz +/- 8.18, lumbosacral spine 91.03 Hz +/- 9.54.

As other research has indicated the cracking sound is composed of multiple frequencies and therefore time scale spectra analysis is inappropriate and might not accurately reflect the true frequency composition of the recorded sound(10). Furthermore, mean frequency calculations will vary considerably depending on the arbitrary signal cut-off point of where the crack signal ends (figure 1) and the sampling frequency range (figures 2a & 2b)).

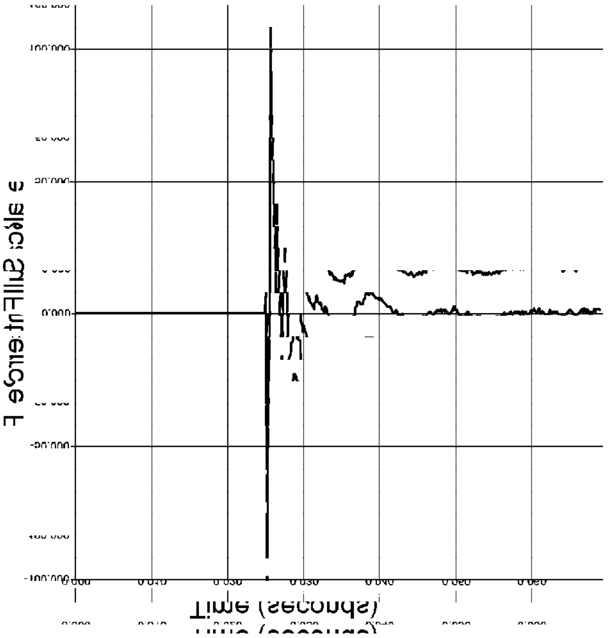

Figure 1: A typical joint crack signal resulting from SMT applied to the cervical spine, in the time and amplitude domains. The signal as shown lasts 70 m secs but this time frame could theoretically be reduced to 30 m secs depending on at what point researcher deems the signal to end.

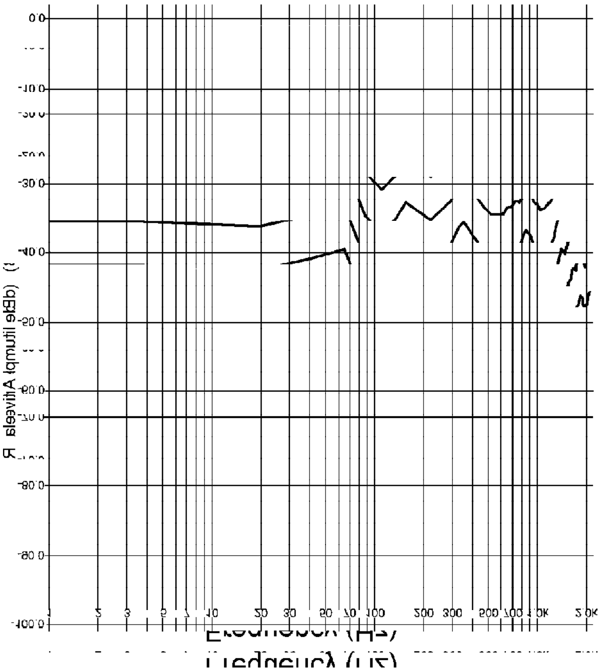

Figure 2a: The same crack signal as depicted in figure 1 but shown in the amplitude and frequency domains. Spectral analysis was performed between 0-2000 Hz resulting in a mean frequency of 1098 Hz.

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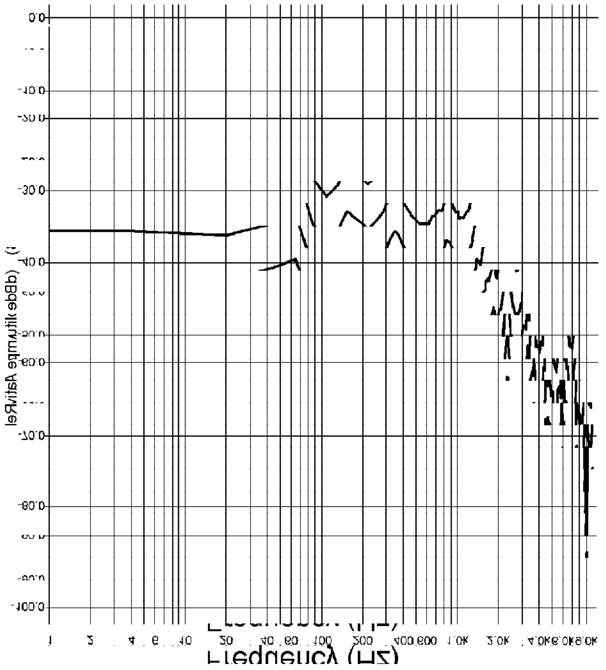

Figure 2b: The same crack signal as depicted in figure 2a but with spectral analysis performed between 0-10,000 Hz resulting in a mean frequency of 4995 Hz but shown in the amplitude and frequency domains.

Woods and West(8) also fails to mention the type of manipulation used and or the spinal level involved. It would not be unreasonable to assume that zygapophyseal joints, even within the same spinal region, would produce different spectrum characteristics due to their different shape, size and orientation. Other researchers have suggested that each joint may have its own unique frequency spectrum(26). Furthermore, the authors fail to mention whether the research was conducted in a quiet or sound proof room. The contamination of the recorded signal by ambient noise may have a significant effect on the accuracy of the recorded signal.

Reggars and Pollard(9) recorded cervical zygapophyseal joint cracking using two small, skin mounted, Electret condenser microphones, connected to a portable DAT recorder (44.1 kHz). The purpose of the study was to determine the side of joint cracking for specific unilateral SMT using fifty volunteers each receiving a single rotatory, diversified, high velocity, low amplitude, thrust technique. The microphones were mounted in a modified syringe cylinder to minimise skin friction noise and attached to the skin on either side of the neck with adhesive tape. The recorded signals were than downloaded onto the hard disk of an IBM compatible personal computer equipped with a 16 bit sound card. The wave forms were then analysed using a commercial wave editing software package using the 44100 samples per second option.

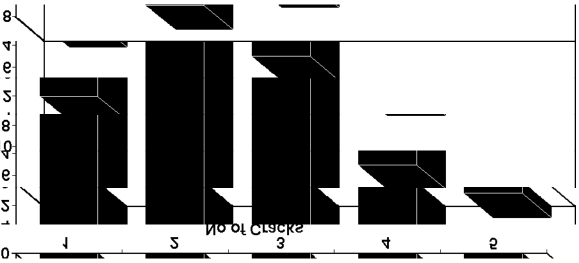

Figure 3: Number of joint cracks per subject.

Although often difficult to discern by ear on analysis the fifty manipulations resulted in 116 individual joint cracking sounds with one subject recording five separate joint cracks. The majority of the subjects (64%) produced more than one crack from the single manipulation and in fact six subjects displayed joint cracking during the pre-manipulative set-up procedure (figure 3). After wave form analysis the average length of the joint crack sound was 170 samples or 4 milliseconds but varied from 834 samples to 17 samples, for individual joint cracks. The wave forms apparently showed no consistent pattern, varying from subject to subject and even within the same subject.

Using the original raw data one the researchers later performed spectra analysis on the DAT recordings of the crack signals(10). However, the signals were processed using a different computer sound card for recording to the computer hard disc. Using a professional quality audio analysis software a total of 123 individual joint crack signals were subjected to Fast Fourier Transform analysis. It is interesting to note that the original study only identified 116 crack signals and according to the author this discrepancy was accounted for by the use of a more sophisticated analysis system in the second study. Full spectral analysis (0-22,050 Hz) showed considerable signal contamination from extraneous noise, including skin friction noise. The author therefore concluded that the calculation of any spectral characteristics apart from peak frequency/amplitude would be of little relevance. As all peak frequency/amplitude measurements were below 2000 Hz final analysis of the parameter was performed between 0-2000 Hz. Peak frequencies for all crack signals ranged from 1.830 Hz to 86 Hz with a mean of 333 Hz (95% C.I., 285-380 Hz) and a median of 215 Hz. No statistically significant difference for peak frequency was evident between pre-manipulative and manipulative joint crack signals. Of the 41 subjects who exhibited multiple joint crack signals 12 (28.6%) displayed at least two signals with the same peak frequency.

Accelerometer Recording

Herzog et al (11-14) appear to be the only researchers who have employed piezoelectric accelerometers to record the vibration signals produced as a result of the articular crack associated with SMT. Their research has primarily concerned itself with the simultaneous recording of the joint crack signals, bone movements, reflex responses and forces exerted during the SMT process. These researchers also claim to be the first to record an SMT associated "cavitation" signal from a cadaver(14). With some minor variations the same technique for the recording and processing of the joint crack signal was employed in all their studies.

Accelerometer Mounting Technique

Either one or two low mass uniaxial accelerometers (Dytran 3115 A) were attached to the spinous processes of the target vertebrae using double sided adhesive tape and the vibration signals were then recorded on an FM tape recorder for later analysis. Several researchers in the discipline of orthopaedics have advocated the use of accelerometers over microphones for recording joint sounds as it is easier to eliminate background noise using accelerometers(27). However, the use of these devices for recording bone vibration may also have its limitations. The reliability and accuracy of the above recording process has been based on some early research(28), which on review, may in itself not be beyond criticism.

Ziegert and Lewis(28) used two low mass uniaxial accelerometers to simultaneously record the vibration signals of both bone and bone/soft tissue in vivo. One accelerometer was attached to the skin surface of the antero-medial tibia using an elastic strap while the second accelerometer was glued to a disc attached to the top of an Eastman 910 needle which in turn was inserted by hand into the adjacent tibial bone. To verify the accuracy of the needle mounted transducer the researchers, using a dry bone specimen, glued one accelerometer to the bone and hand held a second accelerometer needle assembly against the bone surface (figure 4). The bone was then impacted and the two signals compared. As the two traces were nearly identical the authors concluded that the needle mounting procedure was an accurate method of measuring bone vibration.

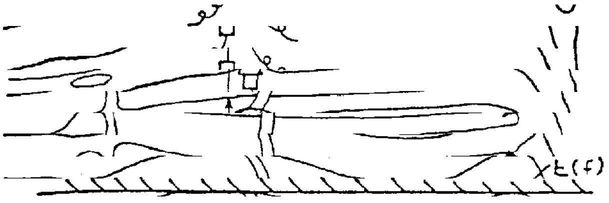

Figure 4: Test mounting procedure after Ziegert and Lewis, utilising bone/needle mounted and skin mounted accelerometers.

After having mounted the accelerometers in vivo, the medial malleolus was impacted for a duration lasting approximately 0.5 msec and the two signals amplified and recorded on transient recorders. This experiment was also repeated using accelerometers with a much higher mass. The signal tracings from the low mass transducers were nearly identical leading the authors to conclude the skin mounted accelerometers can accurately measure bone vibration. The two tracings from the higher mass accelerometers were substantially different, which the authors attributed to the resonance of the accelerometer on the soft tissue excited by the bone motion and was therefore unrelated to the actual bone acceleration.

Several aspects of this research, and for the later research on the spine, bring in to question the accuracy of the measurements obtained using the low mass transducers. The frequency response of the accelerometer will be adversely affected by the described mounting procedure. Briefly, according to the accelerometer manufacturer, the mounting surface would need to be flat in order to obtain a full frequency range, holding the needle by hand may result in frequencies above 1000 Hz being adversely affected and the transducer leads would need to be supported to prevent any triboelectric noise, which again would adversely affect the signal quality. The thickness and rigidity qualities of the needle used to mount the transducer may also have a substantial affect on the quality of the recorded vibration signal (Mitchell BC. Australian Materials Inspection & Testing Equipment. Personal communication). A uniaxial accelerometer also has less sensitivity to vibration in directions other than its main axis which will therefore reduce its capacity to record vibration signals in multiple planes(29).

Other aspects of the spinous process mounting procedure are also contentious. Although the mounting of accelerometers using double sided adhesive tape is acceptable, according to the manufacturer, it substantially affects the transducer's frequency response range. Even the use of thick or thin adhesive tape can have a significant affect on the accelerometer's performance(29). This effect would be compounded when the mounting surface is not firm or flat as in mounting on a spinous process. Further, the soft tissue thickness between the bone and skin surface will have a damping affect particularly in the higher frequency range and diminish the useable frequency range of the transducer. (Change D. Dytran Instruments Inc. Personal communication). As a general indication, for a subject of average height and weight, the shortest distance between the antero-medial aspect of the tibia and the skin surface is 12 mm while for the same individual the shortest distance between the most posterior aspect of the spinous process of T4 and the skin surface is 34 mm while at T11 is 28 mm (Hnatojko M. Radclin Medical Imaging. Personal communication). This rather large increase in tissue thickness may have a profound effect on the quality and accuracy of the recorded signal. Presumably digital palpation was used to identify the target vertebrae but only one study has confirmed, by xray, the mounting sites for the accelerometers. Palpation has been shown to be an unreliable method of detecting bony landmarks(30,31) and the use of this method for the identification of specific vertebrae is questionable. This may have important ramifications with respect to identifying the source of the cracking sound and even for the point of application of SMT.

Signal Processing:
Although not fully described in all their research it would appear that the signals generated by the accelerometers were first amplified and then band pass filtered (3 Hz to 1 kHz), recorded on an FM tape recorder and finally digitised (2000 Hz), and stored on a personal computer.

Some research(10) suggests that some spectral components of the cavitation signal may in fact exceed 1 kHz. By limiting the spectral range to 1 kHz, with the use of a band pass filter, the authors may not be recording the full frequency spectrum of the joint crack and by digitising the signal at only 2000 Hz the possibility of an aliasing effect cannot be discounted.

In some early research(13) designed to ascertain whether the practitioner was capable of determining when cavitation was successfully achieved, a single accelerometer was attached to the spinous process of T3. SMT was applied to T4, using a unilateral, hypothenar, transverse process contact. The authors stated that the acceleration signal produced by the thrust associated with the SMT could be differentiated from the signal produced by the cavitation process and that the practitioner's perception of the occurrence of cavitation during SMT was very accurate.

The authors also concluded that as the accelerometer was affixed to T3, the high frequency signal associated with the cracking sound must have originated from that vertebra. However, the signal may have originated in either of the adjacent thoracic vertebrae or from the surrounding ribs and their articulations with the spine. Further, they state that the "triphasic" shape of the signals associated with the spinal joint cracking sound agree with the wave forms from confirmed cavitation of the MCP joints, except for the duration of the signal. Méal and Scott(7) processed their signals via a full wave rectifier, before hard copy recording. This process in essence alters the original signal to produce a wave form with positive amplitude values only making any worthwhile comparison extremely difficult (figures 5 & 6).

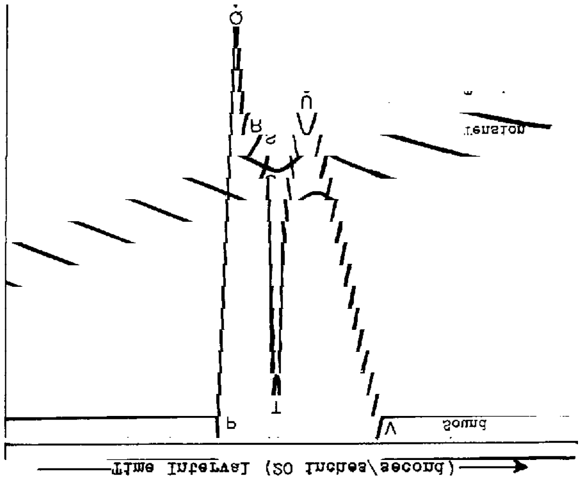

Figure 5: Joint crack wave form of MCP joint recorded by microphone and using full wave rectifier showing all amplitude signal above the x axis (after Méal and Scott).

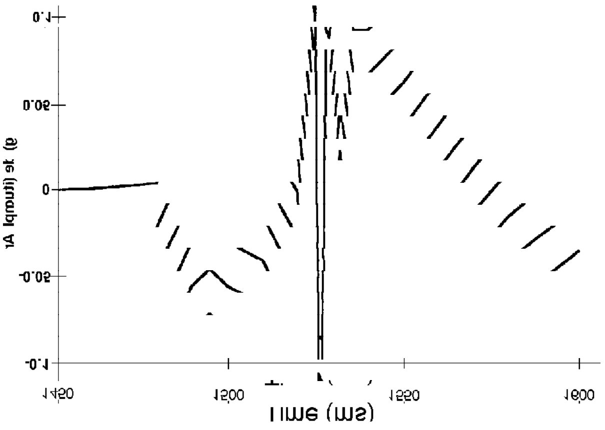

Figure 6: Joint crack wave form recorded by T3 spinous process mounted accelerometer showing amplitude signal both above and below x axis (after Herzog et al).

CONCLUSION

It would appear that both currently used techniques, microphones and accelerometers, suffer from some inherent disadvantages when used to record the joint cracking sound associated with SMT. Some worthwhile information may be gained by conducting further research into the joint crack phenomenon, particularly with respect to spectral analysis. However, before this research is undertaken a more reliable and accurate means of capturing and processing the joint crack signal needs to be established.

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