Vibration arthrometry

A preview

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Throughout the ages, physicians have listened to sounds and felt vibrations from human joints in their attempts to diagnose pathology. They have used a wide vocabulary to describe these phenomena, but technology has been slow to provide recording and analytic equipment. Lately, accelerometers have been used with considerable success in a new noninvasive method now known as vibration arthrometry (formerly "arthrography"). The technique has been used in early detection of congenital dislocation of the hip and also in diagnosis of meniscal pathology. More recently, patellar vibration has been used to assess the mechanical properties of articular cartilage. Vibration arthrometry has also yielded new information on a possible damage mechanism associated with shock vibration that arises during cavitation of synovial fluid. Joint vibrations are therefore useful aids to diagnosis and may even be etiologic in orthopedic disease.

Knäppningssymptomet is the Swedish word that Palmén (1957) used to describe a phenomenon detected by those examining the unstable neonatal hip. Language, however, provides a very limited spectrum of words describing sound and vibration. The various events that are elicited from the locomotor system have been verbally described as **click** (*klick*), **clunk** (*knäpp*), and **crepitus** (*knirk, knak*). These words attempt, in a limited and subjective way, to describe what is detected using the sense of touch in feeling or palpating human joints as they are examined. Confusion has arisen in interpretation and communication due to the absence of objectivity, and this has had serious consequences. Ortolani (1937) in his description of the pivot shift of the neonatal unstable hip from a dislocated or subluxed position into the reduced position during the abduction test used the Italian word, *scatto* which is open to interpretation and may be translated into the English word **release** or **jerk**. In reality, however, it became click. This was unfortunate, because clicks from the neonatal hip and knee occur in about 10 percent of neonates and, in the majority of cases, do not represent underlying pathology. The word **clunk** would have been a more appropriate translation. Clearly, there was not only a need to get the nomenclature correct, but one has to ask: Why, in this world of high technology, are there no objective methods to define and characterise these events? The presence of sounds and palpable events are universally used by clinicians to diagnose pathology in the locomotor system, e.g., congenital dislocation of the hip, torn menisci, and chondromalacia patella. These sounds are also used as an indication of disease, for example: the crepitus produced in arthrosis. However, no useful objective test to detect and quantify these events has been developed for clinical use, and it is clear that this problem needs further investigation.

History

Laennec (1848), constrained by propriety while examining a female patient, created a device to auscultate the heart while he remained at some distance

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from the skin. He then discovered and developed the stethoscope. In scientific terms, he found that the rolled quire of paper acted as a simple wave guide to transmit, in a very efficient way, vibrations in the acoustic range. The first use of the stethoscope to investigate the locomotor system was reported in the appendix of his thesis. Here, Laennec admitted to a lack of time to carry out this work because of the pressures of his investigation into cardiac and respiratory disorders, and he reported the work of Lisfranc, who claimed to be able to diagnose difficult ankle fractures and other pathology by use of the newly invented device (See Appendix, p. 79).

The first reference to the exclusive use of auscultation to the locomotor system was by Heuter (1885). He modified a stethoscope and called it a myodermato-osteophone. He claimed to be able to locate loose bodies within the knee joint and also assess the roughness of articular cartilage using this device. Blodgett (1902) used a rubber ring on a stethoscope in an attempt to overcome the problem of skin friction noise and related knee joint sound to flexion angle of the knee. He realized the potential of the method and pleaded for further investigation.

The succeeding three decades realised his wish with work by Ludloff (1906) on the spine, Bircher (1913) on the knee and a mammoth investigation of Walters (1929) of 1600 joints in an attempt to document the range of normal knee sounds. Erb (1933) recognized the technical problems of source location in joints and the inherent insensitivity of microphones. Later work by Steindler (1937), Peylan (1953), Ekensten (1952), Fischer and Johnston (1960), Radochay et al. (1965, 1966), and Chu et al. (1976a, b, 1978), despite increasing sophistication in electronic analysis, failed to solve the problems of detection.

It was clear that the microphone sensitivity was diminshed by skin friction and ambient noise, which swamped all but the most obvious events. Working independently and unaware of each other's interest, Mang et al. (1980) and Mollan et al. (1981, 1982, 1983a) confirmed that it was the sensor, the microphone, that was the essential problem. By their nature microphones integrate sound arising from a region of space, lacking a focus point, so preventing precise vibration measurement at a point. Furthermore, because of the mechanical advantage of direct transmission of the vibrations to the sensor, the most appropriate detector of these events was the accelerometer. Comparative studies by Mollan (1981) and later by McCrea et al. (1985a) have demonstrated this and have shown the extensive potential of vibration arthrometry (Kernohan et al. 1986b).

The accelerometer

The accelerometer is the basis of the new technique called vibration arthrometry. Essentially the accelerometer, being highly sensitive to vibration in a particular plane, "palpates" the structure under examination. Often vibrating structures are described using a system of rigid bodies, springs, and dampers. When the human body is looked upon as a mechanical structure, it contains a number of rigid bodies linked together. The head may be thought of a single rigid body linked via one spring and one damper to the upper torso, itself a rigid body with further spring and damper attachments (Coerman et al. 1960). In the same way the bones of the lower limb may be regarded as rigid bodies linked by spring and damper.

When vibration is induced during vibration arthrometry, the accelerations and decelerations are detected in the direction of the accelerometer casing. The high degree of directionality of the sensors was extremely useful when interpretation of the events was undertaken. Each accelerometer consists of a metal case within which is a piezoelectric crystal that has a mass resting on it. This crystal reacts to acceleration by producing a minute electric charge between its top and bottom surfaces, due to the compression produced by the mass, which is directly proportional to the acceleration. This charge is approximately 300 $pC{\cdot}m^{-1}{\cdot}s^{2}$. This is then input to an amplifier of high input impedance prior to being recorded as a vibration signal. This type of transducer can be made to small dimensions so that the structure under examination is not excessively loaded and the signal is not effected. Artefact signals were easily distinguished from true vibration signals (Mollan et al. 1983b). The signals are not substantially effected by ambient or skin friction noise but the fact that they are directional must be kept in mind when they are orientated around joints.

Methods

In clinical practice accelerometers are applied to the skin with adhesive tape suitably incised to adhere to the transducer casing and the emerging wire, holding both firmly to the surrounding skin with a force of the order of 4–5 N.

During the early stages in the development of vibration arthrometry, the accelerometer signals were recorded on an FM tape recorder (Brüel & Kjær type 7003). Recordings were then replayed into an ink-jet pen recorder for identification (Elema-Schönander Mingograf 34). In vibration arthrometry

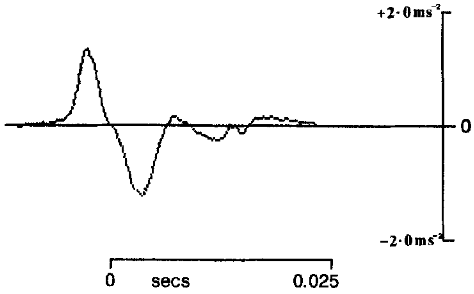

Figure 1 Computer-generated view of neonatal hip vibration. This child was a member of the "safe click" group. A transient vibration was felt by the examiner, but no abnormality was seen. The peak frequency of the acceleration signal was 93 Hz and the acceleration range was 2.4m·s^{-2}.

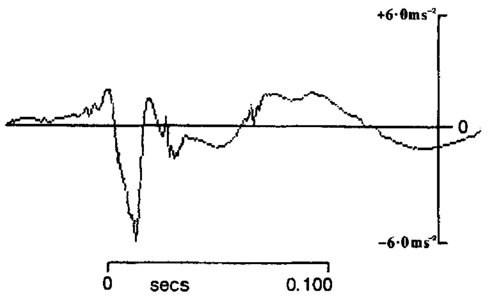

Figure 2 A clinically unstable hip also produces a transient vibration. The peak frequency of this example was 45 Hz and the acceleration range was 7.7m·s^{-2}.

Table 1. Definition of clinical groups in the congenital hip dislocation (CDH) pilot study

Neonatal findings	n	Children with signals	Children with bilateral signals	No. of vibration episodes	Mean peak frequency Hz	*SE*	Outcome
Normal	53	19	7	36	29	*8*	Normal
Click	201	156	133	434	118	*6*	Normal
Click	16	15	15	49	67	*14*	CDH
Clunk	14	10	8	48	31	*11*	CDH
Not seen at birth	22	13	4	62	36	*10*	Late CDH

of the knee a goniometer was used to simultaneously record knee angle.

The signals of particular interest were replayed and subjected to analysis using the fast Fourier transform. This is a mathematical method that breaks the vibration into its component frequencies and is based on the principle that any signal can be described as a sum of sine and cosine waves. The *peak frequency* parameter is the frequency that contributes most power to the signal and the *level of the peak frequency* is the value of this power in decibels.

The Fourier transform was carried out using a narrow band spectrum analyser (Brüel & Kjær Type 2031) and recorded on an XY plotter. A laboratory interface (IEEE488) from the analyser to a microcomputer system permitted further calculations on the time signals (Kernohan 1982). Results of analysis included both time-domain and frequency-domain parameters.

With transient signals the most relevant parameters were found to be acceleration range, pulse area, and peak frequency.

In repetitive waveform patterns, such as crepitus, acceleration range, peak frequency and repetition frequency were the most relevant measurements. The peak frequency was obtained from the Fourier transform and the repetition frequency was available from the time domain signal. Software was devised to compute these variables and to map the areas of vibration throughout the joint cycle (Kernohan and Mollan 1983b). The detection and analysis system was deliberately chosen to be flexible and of a high technical specification so that information was not lost due to insensitivity or filtering.

Hip dysplasia pilot study

The above methods of vibration arthrometry have been applied to detect vibration events during examination of infant hips (Cowie et al. 1984). Characteristic vibration signals were found from hips that clinically presented with a click (Figure 1) or a clunk at birth (Figure 2) or a clunk from late congenital dislocation of the hip. During routine testing, by pediatric staff, neonates who were found to have a click or any palpable vibration in either hip were referred for vibration arthrometry. In addition to this group, a small control group was investigated. On later review, at 4 years of age, the children were again assessed by the same method. In this study, five distinct clinical groups were defined (Table 1). The sole difference between normal and click cases

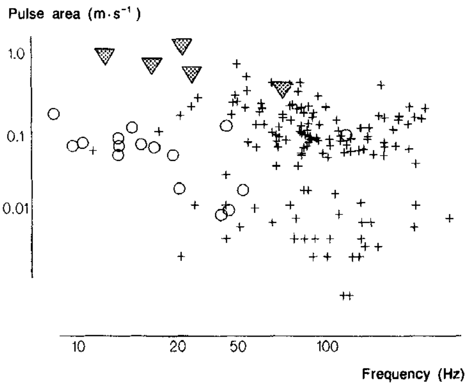

Figure 3 In vibration arthrometry for CDH the hip vibration was measured giving an acceleration signal. The main results of analyzing these, and future signals, may be plotted on this chart to assist diagnosis. Vertical scale is pulse area ($m \cdot s^{-1}$), horizontal scale is average peak frequency (Hz) for each episode (both scales logarithmic). The unstable cases (▼) were in the low frequency, high pulse area, the safe click group (+) were in the high frequency, low pulse area, and normal cases (o) were in the low frequency, low pulse area.

Table 2. Clinical groups in the vibration arthrometry of 247 symptomatic knees. + indicates meniscal signal recorded and – indicates no signal

N	Vibration findings	Arthroscopic findings
43	+	Bucket handle tear
57	+	Posterior horn tear
26	+	Miscellaneous tear
24	+	Mobile meniscus
8	–	Small tear
10	–	Locked knee and tear[a]
6	–	Effusion and tear[b]
73	–	No abnormality detected

[a] either bucket handle or posterior horn
[b] generally posterior horn

was that clicks were felt by the examiner while normals had no vibration felt. However, vibration arthrometry revealed that some normals (19/53) give low level hip vibration. Sixteen click cases went on to develop dislocation. These had a low peak frequency differentiating them from the other clicks. Neonates with hip instability at birth produced the distinctive clunk signal of low frequency and high amplitude.

Of the total, 213 (70%) were positive on vibration arthrometry, i.e., at least one vibration episode was recorded. The remainder had no vibration recorded either due to technical difficulties or because no vibration was produced. Of the positives, 167 (78%) were bilateral. Each hip was tested at least once, but up to 12 episodes were recorded in an unstable case.

As the diagnostic potential of the system became clear and large numbers of signals required analysis, the recorded information was statistically analyzed. Of the vibration parameters, pulse area and peak frequency were found to be of particular value in congenital hip dislocation. A one-way analysis of variance for pulse area and frequency (after log transform) against clinical group gave $P < 0.005$ and $P < 0.0005$, respectively. Methods of statistical discriminant analysis were used to find a function or combinations of parameters that could help diagnosis. These functions generate allocation probabilities that can be used by a clinician to make appropriate decisions about patient management (Kernohan et al. 1989). The method would not require a clinician to analyze the vibration signal by eye, or to classify by parameter, although it is possible to detect subtle differences in appearance of signals from the different clinical groups. A scatter graph of peak frequency for each hip vibration against pulse area (Figure 3) could be used to predict clinical outcome; and its performance on the test data was assessed to give an overall correct classification rate of 93 percent. This is currently under more rigorous clinical evaluation in a study of 3,000 randomized cases.

Diagnosis of knee pathology

Vibration arthrometry has also been applied to detect and record vibration emission during examination of the knee (McCrea et al. 1985b, McCoy et al. 1987).

In a 1-year study, patients admitted for arthroscopy agreed to undergo vibration arthrometry. The accelerometers were positioned over the medial and lateral femoral condyles and over the patella. An electrogoniometer was used to record knee angle during both active and passive testing. Arthroscopic findings were used to correlate recorded signals with observed pathology.

Of 247 patients who underwent surgery for acute knee injury, 172 were demonstrated arthroscopically to have meniscal lesions, and of these 150 (87%) produced typical meniscal signals (Table 2). The meniscal signal is characteristic with the vibration detected simultaneously on all three channels, and is always being largest on the affected side. The mean peak frequency of the signal detected on the affected side was 118 (25–338) Hz. The mean size of the shock was 4.8 (1–35) $m \cdot s^{-2}$. In a series of 150 signal

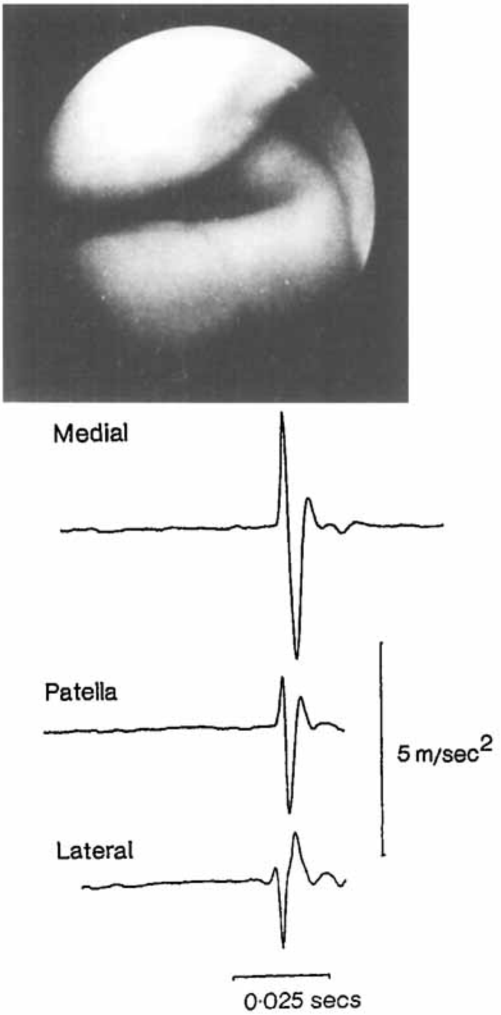

Figure 4. An example of vibration output from three accelerometers positioned around a knee that presented arthroscopically (inset photograph) with a Type I bucket handle tear of the medial meniscus. The maximum recording was from the affected side.

producers, there were 85 cases of medial and 65 lateral meniscus injuries. A variety of meniscal pathology was observed with varying signal patterns.

Bucket handle tears were observed in 43 of the subjects who produced signals. A Type I tear produced the vibration episode in mid-swing close to 45° with a maximal acceleration from the affected side, the next largest from the patella and the contralateral signal smallest (Figure 4). Type III tears, which tend to lie posteriorly, produced signals at greater degrees of flexion, close to 90°. The signals appeared with maximal acceleration from the affected side, while the next largest was recorded from the contralateral side, and furthermore, the minimum acceleration was seen from the patella.

A posterior horn tear was observed with characteristic signals in 57 cases. Again, the largest signal occurred on the affected side with a noteworthy contralateral signal, but a minuscule patellar signal; posterior horn vibration episodes arose near maximum flexion. Vibration was recorded of a similar nature from 24 cases in which the meniscus was unduly mobile. The remaining 26 presented with miscellaneous lesions, such as horizontal cleavage tears or radial cystic tears. In 24 cases (14%) a false negative result was obtained; 10 of these had a locked knee.

It has been postulated that such meniscal vibration originates from a rigid body movement caused by a deviation in roll-glide occurring during knee motion. Furthermore, that the signal itself is the result of a sudden return to normal movement after temporary interruption of the roll-glide by soft tissue interposition (McCoy et al. 1987).

The use of vibration arthrometry before and after corrective surgery indicated that the method can be used to obtain an objective assessment of the efficacy of arthroscopic surgery. In a group of patients who had undergone meniscal resection some cases showed a reduction in the energy of the vibration signal to less than one tenth of the preoperative value (McCoy et al. 1988).

Moreover the technique permits localization of the meniscal injury—both in terms of anterior/posterior as well as medial/lateral—by examining the relative sizes of the waves recorded at the three accelerometers. A further development in this area employed circles of possible source points in an attempt to localize pathology based on a premise of uniform wave propagation (Kernohan et al. 1983a), but this assumption was later put in some doubt by Beverland et al. (1985a, b, c, d, 1986), who emphasized the rigid body movement of the patella during vibration arthrometry; see below.

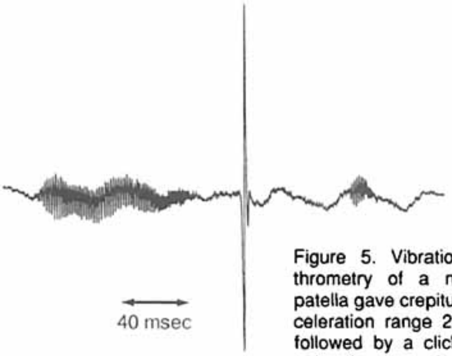

Figure 5. Vibration arthrometry of a normal patella gave crepitus (acceleration range 2m·s^{-2}) followed by a click (acceleration range 8m·s^{-2}).

Patellar clicks

When the normal knee is the subject of vibration arthrometry it is possible to record both single transients and series of transient vibrations as the knee is freely flexed and extended, for example, from the patella (Figure 5). Such transient vibrations or patellar clicks are frequently audible and of considerable acceleration (over 10 $m \cdot s^{-2}$ peak to peak) and occur only once in each joint cycle. These clicks occur at a repeatable joint angle on extension of the knee and only at angular velocities greater than 5 $°s^{-1}$. The reproducibility, as indicated by the ratio of standard deviation/mean joint angle, was less than 0.04. Repetition is seen to have an inhibiting effect on the patellar click amplitude, which has been seen to diminish in acceleration level by 7 percent per cycle of limb movement. The frequency parameter showed no such diminishing trend. The signal disappeared into the background-noise level after several cycles of knee joint movement (Kernohan 1983c).

The etiology of the transient patellar click is uncertain. It is, however, a normal phenomenon. Joint exercise clearly acts in some way to alter the joint mechanics, so that with each cycle of movement the click was reduced in amplitude. We believe that the smooth movement of the patella is interrupted as the area of contact crosses the transverse ridge on its underside. Thus, in slow extension no sudden traversing is evident, while in rapidly moving from one facet to another, a transient vibration is recorded. By repetition, this cartilage ridge may become flattened, so reducing the effect.

In brief, the patellar click is a normal phenomenon, occurring at approximately 55° during knee extension; it is frequently absent in patients with patellar symptomatology (Beverland 1985e).

Physiologic patellar crepitus

When the normal knee is flexed or extended at about 3° per second, a characteristic signal, consisting of a series of transients or vibration beats, can be detected over the patella (Beverland et al. 1985c, Kernohan et al. 1986a). The positioning of the transducer is critical, affecting both amplitude and phase. A point near the center of the patella gives a very low output while points near the upper and lower poles give maximal output, but opposite phase, indicating a basic see-saw rigid body vibration (Figure 6). Frequency estimates of this vibration are difficult because two components from different sources pertain. One component arises from an inherent spectrum (in one beat) and a second from the repetition frequency (Beverland et al. 1985a). The inherent component has been estimated using a weighted-mean calculation (Beverland et al. 1985d), while the repetition component has been estimated in the time domain by a cross-over method.

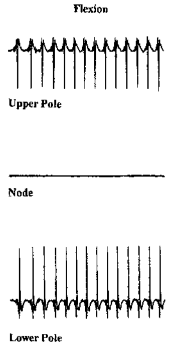

Figure 6. Vibration arthrometry of a normal patella during flexion yielded three recordings of patellar vibration: from the Upper Pole, Node, and Lower Pole. Maximum acceleration range 2$m \cdot s^{-2}$.

A model built by Beverland (1986) indicated that the beats occur as a result of stick-slip friction between the patella and femur. The signal is produced during conditions of boundary lubrication (Beverland 1985e). The amplitude and frequency of the beats were found to be very sensitive to angular velocity and joint loading. If the angular velocity is kept below 5 $°s^{-1}$ and is controlled passively by a continuous-passive-motion-type apparatus, a continuous signal can be produced in all normal joints. The grossly arthrotic patellar joint when moved under the same conditions produces no signal.

The friction coefficient between normal cartilage surfaces increases after an isometric load due to the increased coefficient of friction that occurs in normal cartilage undergoing creep deformation with load (Beverland et al. 1985b), and this affects the amplitude of recorded vibration. In this way the vibration emission can be used in noninvasive assessment of the integrity and characteristics of the patellar articulation.

Cavitation damage in human joints

An interesting release of vibrational energy occurs when human joints are distracted, for example the well-known cracking sound from the metacarpophalangeal joint. The energy release has been assigned to *vaporous cavitation*, a fluid bubble activity, occurring when the pressure in the synovial fluid is reduced below the vapor pressure and a bubble of vapor is created in the joint space.

Watson et al. (1989b) describe an individual whose intense joint cracking activities may highlight a potential for damage. The individual admitted fre-

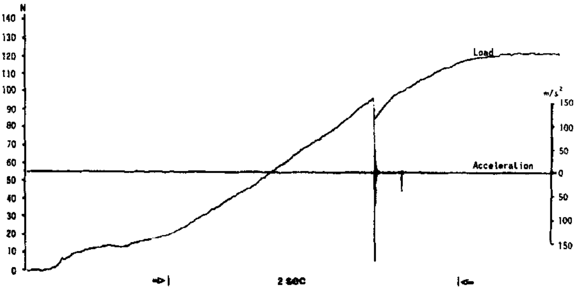

Figure 7. Graph of load across the metacarpophalangeal joint against time together with a simultaneous vibration arthrometry recording of acceleration range 300m·s^{-2} during joint distraction.

quent, even habitual, knuckle cracking, up to 25 times daily. Radiographic evidence of ligamentous ossification and chondrocalcinosis was present.

Joint cracking at the time of distraction has been studied using a motorized device that simultaneously monitored the load on the joint and its distraction (Watson 1988a). A 23-year-old subject placed his hand, palm down, on the device with a finger splinted to permit continuous distraction at speeds of up to 4 mm·s^{-1} with loads not exceeding 200 N. Both cracking and noncracking distractions of the second and third metacarpophalangeal joints were performed first at room temperature and resistance to elongation or stiffness was calculated. Vibration arthrometry was implemented concurrently by attaching an accelerometer to the skin over the joint. The measured load during distraction was seen to rise slowly and then drop sharply if the crack occurred (Figure 7); a transient vibration signal appeared simultaneously from the accelerometer.

Each joint examined was at least 15 percent stiffer during cracking distractions. Conversely, during a normal noncracking distraction, the joint was more lax ($P < 0.05$). The same experiment was performed at 45 ℃ and 9 ℃ with a resulting doubling in stiffness at the lower temperature. This can be expressed as a variation in stiffness of 0.33 N·mm^{-1}·℃$^{-1}$. Through these experiments it was also possible to assess energy release by integrating the accelerometer recording to give pulse area. An example value of pulse area is 0.274 m·s^{-1}, which represents approximately 6 mJ of energy. Moreover, values have been recorded up to 10 times this value which shows the potential of cartilage damage through this mechanism.

Two forms of cavitation are hypothesized in synovial joints:

1. *Macrocavitation,* responsible for the large scale audible cracking sounds. The cracking sound is associated with the appearance of a bubble filling the joint space when viewed on a radiograph.

2. *Microcavitation,* currently being investigated as a source of etiologic lesions in arthrosis. Crater-like lesions were produced by ultrasonically generated microcavitation in vitro on specimens of bovine articular cartilage (Watson et al. 1989a), which bore close resemblance to those seen in arthrosis and reported in joint immobilization studies. Cavitation through the more physiologically representative action of suction also created these lesions in vitro (Watson and Mollan 1988b).

Thus, vibration output is more than a diagnostic sign of joint pathology; and the vibration itself may be an etiologic agent in arthrosis.

Towards a bedside screener for vibration arthrometry

While a useful research system, it was clear that vibration arthrometry should evolve in a different direction. The analogue system described above was not only expensive, but was time consuming in operation. Analysis was, for the most part, separate from the patient in terms of time. In each clinical situation, for example, examination of the neonatal hip or the examination of the adult knee, the noninvasive test should result in an instant display of the event detected and a rapid analysis of signal to aid interpretation. Ideally, this should incorporate the ability to monitor the execution of the test. The route taken was to build a microcomputer-based prototype screener where the analogue amplifiers and filters for the sensors were a custom built part of the analogue-to-digital convertor. An early screener described by Shaw et al. (1985) was based on an Apple IIe microcomputer. Assembly language software was written to capture vibrations from the neonatal hip, then display the vibration signals, and finally to analyze selected windows of vibration such as clicks or clunks.

The signals were initially stored in memory and then displayed once the test was completed. Advances in computer technology now permit instant display and storage of the vibration events economically (Lamb 1987). Custom software carries out analysis appropriate to the clinical problem and the analysis of the event is displayed. This analysis is then related to the database assembled from clinical trials and a statistically-based interpretation provided.

The first bedside diagnostic system has been passed by the British Standards Institute and is now undergoing a clinical trial. This particular device is dedicated to early screening for congenital dislocation of the hip; but, because the technology is similar for all vibration arthrometry, the long delay between prototype and approved device in this case should be circumvented when devices are produced for the knee and other joints.

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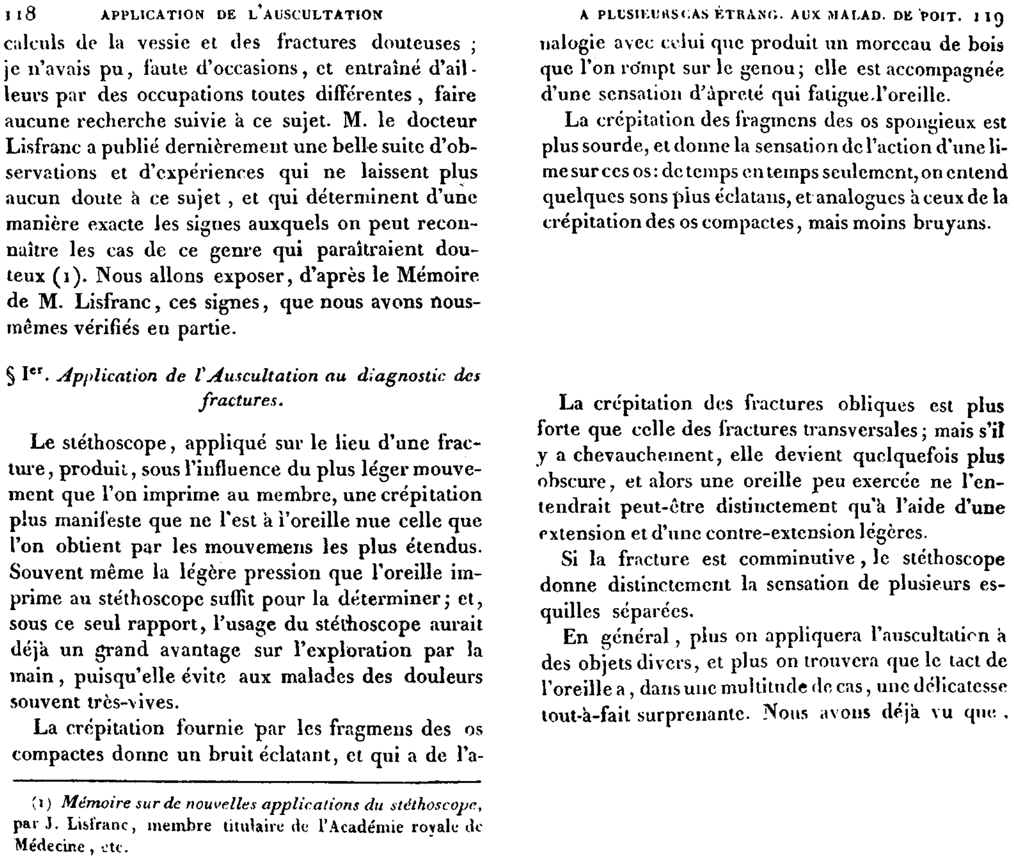
Appendix

Excerpts from pages 118 to 119 from Laennec R-T-H. *Traité de l'auscultation médiate et des maladies des poumons et du coeur.* Chaudé, Paris, 1826.

In his pioneer work Laennec referred to clinical and animal experiments by Jaques Lisfranc on auscultation in the diagnosis of fractures. The examples reproduced here show that Lisfranc could distinquish between fractures of compact and spongious bone; and between spiral and transverse fractures; he heard distinctive sounds from comminuted fractures.



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calculs de la vessie et des fractures douteuses ; je n'avais pu, faute d'occasions, et entraîné d'ailleurs par des occupations toutes différentes, faire aucune recherche suivie à ce sujet. M. le docteur Lisfranc a publié dernièrement une belle suite d'observations et d'expériences qui ne laissent plus aucun doute à ce sujet, et qui déterminent d'une manière exacte les signes auxquels on peut reconnaître les cas de ce genre qui paraîtraient douteux (1). Nous allons exposer, d'après le Mémoire de M. Lisfranc, ces signes, que nous avons nous-mêmes vérifiés en partie.

§ I^er^. *Application de l'Auscultation au diagnostic des fractures.*

Le stéthoscope, appliqué sur le lieu d'une fracture, produit, sous l'influence du plus léger mouvement que l'on imprime au membre, une crépitation plus manifeste que ne l'est à l'oreille nue celle que l'on obtient par les mouvemens les plus étendus. Souvent même la légère pression que l'oreille imprime au stéthoscope suffit pour la déterminer; et, sous ce seul rapport, l'usage du stéthoscope aurait déjà un grand avantage sur l'exploration par la main, puisqu'elle évite aux malades des douleurs souvent très-vives.

La crépitation fournie par les fragmens des os compactes donne un bruit éclatant, et qui a de l'analogie avec celui que produit un morceau de bois que l'on rompt sur le genou; elle est accompagnée d'une sensation d'âpreté qui fatigue l'oreille.

A PLUSIEURS CAS ÉTRANG. AUX MALAD. DE POIT. 119

La crépitation des fragmens des os spongieux est plus sourde, et donne la sensation de l'action d'une lime sur ces os: de temps en temps seulement, on entend quelques sons plus éclatans, et analogues à ceux de la crépitation des os compactes, mais moins bruyans.

La crépitation des fractures obliques est plus forte que celle des fractures transversales; mais s'il y a chevauchement, elle devient quelquefois plus obscure, et alors une oreille peu exercée ne l'entendrait peut-être distinctement qu'à l'aide d'une extension et d'une contre-extension légères.

Si la fracture est comminutive, le stéthoscope donne distinctement la sensation de plusieurs esquilles séparées.

En général, plus on appliquera l'auscultation à des objets divers, et plus on trouvera que le tact de l'oreille a, dans une multitude de cas, une délicatesse tout-à-fait surprenante. Nous avons déjà vu que.

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(1) *Mémoire sur de nouvelles applications du stéthoscope*, par J. Lisfranc, membre titulaire de l'Académie royale de Médecine, etc.