Vibration Arthrography in Ulster

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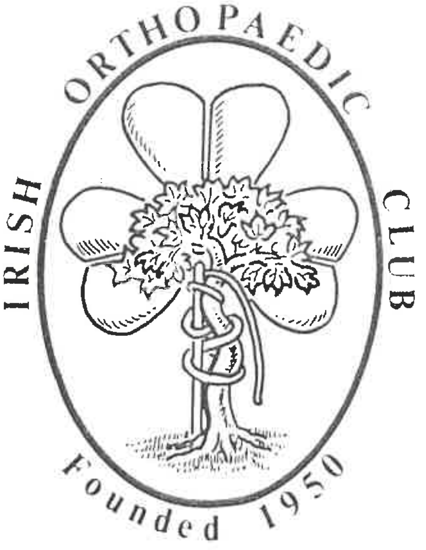

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INTRODUCTION

The detection and recording of vibration signals from human joints, a technique which we have termed "vibration arthrography," is a sensitive, non-invasive method for the objective study of the locomotor system. The technique itself is relatively recent in origin, dating essentially from the work of Mollan and his co-workers in Belfast. In using vibration sensores to detect the vibration signals from joints, Mollan was able to overcome the shortcomings inherent in earlier acoustic systems; chiefly the poor response of microphones to low frequency signals and signal distortion caused by skin friction background noise.

The acoustic evaluation of joints has a much longer history, dating back over 100 years. In 1885, Heuter reported the first study involving the interpretation of sounds from human joints when he described the localisation of loose bodies within the knee using a stethoscope. Subsequent studies also involved stethoscopic examinations of the joints but the subjective nature of these reports was recognised by Erb. In an effort to reduce this subjectivity Erb recorded joint sounds using a microphone attached to an oscilloscope which could produce a graphical account of the signals detected. Many microphone based studies followed the initial report of Erb but, despite increasing sophistication in both recording and analysis of signals, the problems of poor response at low frequency and of background distortion remained.

In 1960, Mang et al published the first study of the locomotor system using vibratio sensors as detectors. They did not appear to realise the significance of their choice of sensor, nor did they discuss the reasons for this choice. Mollan, working independantly of Mang, described the considerable advantages of using vibration sensors to detect joint signals. Vibration arthrography is now becoming established as a new non-invasive technique for the investigation and diagnosis of locomotor joint disease (1). A bibliography of the above history is contained in the reference quoted. This paper reports our early experience of vibration arthrography as applied to the knee joint and discusses the future clinical development of this technique.

MATERIALS AND METHODS

The vibration detection system employs vibration sensitive sensors known as accelerometers. These accelerometers are sensitive by producing a small variable voltage. Their small size (less than 2g) and the fact that they can be securely fixed avoids skin friction noise. The output from these sensors was amplified and recorded onto a 4-channel FM tape recorder, the signals recorded being simultaneously monitored on an oscilloscope. Analysis of signals recorded involved replaying the tapes at "real time" through the oscilloscope to indentify the sections of interest, and subsequently, these sections of interest were replayed at one-eighth speed for detailed analysis. A modified ECG machine gave an analogue record of the signals being analysed. The signals were fed into a spectrum analyser linked to a microcomputer to permit computation and storage of the signal parameters. Using this apparatus it was possible to describe signals in terms of the size of the shock (acceleration range), power content (root mean square of RMS) and peak frequency (Hz.).

Both normal subjects and those with symptomatic knees were studied. The symptomatic subjects were patients admitted from the waiting list for arthroscopy. In these subjects the accelerometers were positioned over the medial and lateral femoral condyles and over the patella, sites which had previously been shown to be optimal for such recording. An electronic goniometer strapped to the lateral aspect of the limb recorded the position in the limb cycle at which signals occurred. Subjects were examined seated, with the limb free to flex and extend without impingement. The test sequence included two, four and six second active cycles (a cycle being defined as one complete movement from 90 degrees of flexion to full extension and back to 90 degree of flexion again) and, valgus, varus and McMurray stress cycles. The normal subjects had no past history of knee joint disorders and comprised mainly hospital workers, secondary school students and industrial workers. The test sequence in these normal subjects included slow active knee cycles and the accelerometers were positioned during such testing over the patella. Using the method described we studied the vibrational output from 250 normal and 247 asymptomatic subjects. A proportion of those who underwent arthroscopic menisectomy were submitted to vibration arthrography three months to one year following surgery.

RESULTS

Two hundred and forty-seven patients admitted for arthroscopy at our orthopaedic centre in a twelve month period also underwent vibration arthrography. Of these, 172 were demonstrated arthroscopically to have a meniscal lesion and 150 of these produced characteristic signals (diagnostic accuracy = 86%). The meniscal signal is quite unique and is produced by no other intra-articular pathology. Neither is it observed in normal knees moved through the same test sequence of fast active and passive stress cycles. A meniscal signal results in a simultaneous signal from all three accelerometer positions with the maximal signal always observed over the femoral condyle on the affected side. It is not an isolated phenomenon, but is observed repeatedly at approximately the same angle in the limb cycle. In this study signals were abserved from 85 cases of medial meniscal injury and 65 cases were the lateral meniscus was affected.

A variety of meniscal pathology was observed, and the signal patterns recorded varied according to the meniscal lesion present. With a complete (Type I) bucket-handle tear, the signal characteristically occurred in mid-swing, close to 45 degrees. With this type of lesion, the maximal desplacement is observed, as is usual, on the affected side. The second largest signal is seen over the patella, with the smallest signal on the contralateral side (Fig. 1). With a Type III lesion, occuring more towards the back of the joint, signals are generally observed at a greater degree of flexion (in the range 70-85 degrees). Here the second largest signal is seen not over the patella but on the contralateral side. With a true posterior horn tear, the signal tends to occur at 90 degrees or greater, and the signal observed over the patella can be very small indeed (Fig. 2).

Surgery was demonstrated to have a profound effect on the meniscal signal. Twenty-six of the 150 signal producing subjects, selected at random, were reviewed and recorded post-operatively. In 18 subjects, resolution of the symptoms was accompanied by complete disappearance of the signal (Fig. 3). In five subjects, minimal signals persisted and in these cases a much diminished signal was recorded post-operatively, with the signal shock less than one-tenth that observed pre-operatively. In three subjects, the meniscal signals persisted undiminished in association with persistance of significant symptoms.

The synovial plica was also demonstrated to give a characteristic signal. Plicae become symptomatic when they impinge on the femoral condyles during the normal excursion of

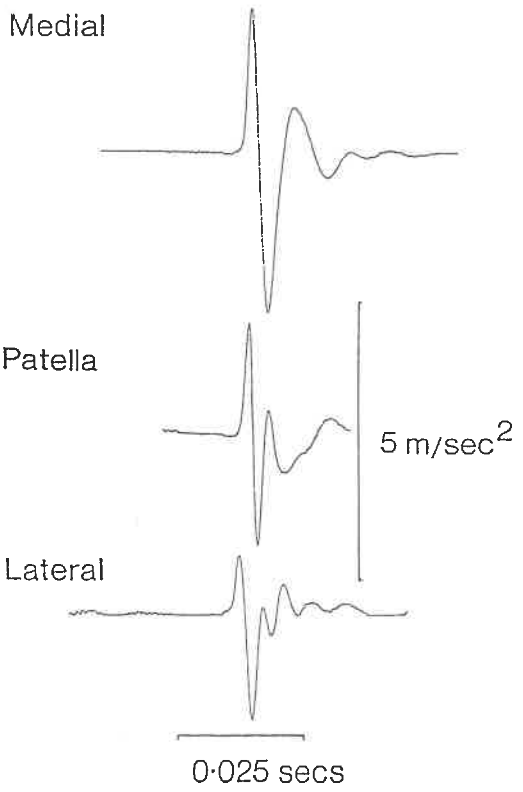

FIG. 1

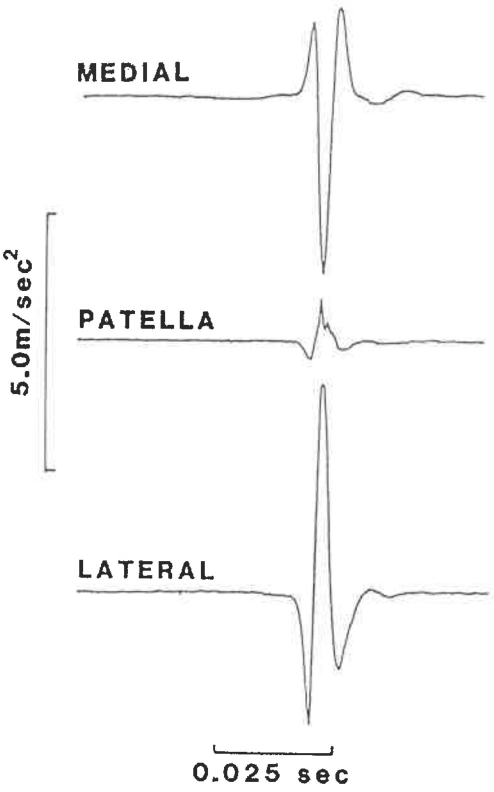

FIG. 2

the knee joint. The plica therefore acts in the manner of a bow-string as it moves across the femoral condyle and the signal produced during flexion is opposite from that produced by extension. The tracing from a synovial plica produces an initial negative deflection in flexion and a positive deflexion in externsion. The plical signal is abolished by appropriate surgery.

In all normal subjects a palpable patellar vibration is produced when the knee is moved slowly. We have called this vibration "Physiological Patello-femoral Crepitus" or PPC. It is only with advanced degenerative disease of the patello-femoral joint that the phenomenon is not observed. The amplitude and characteristics of the PPC signal vary greatly with accelerometer location and the direction of knee movement. When the accelerometer is attached to the lower pole of the patella, the waveform is peak positive in flexion and peak negative in extension. If a simultaneous recording is made from the upper pole, the waveform observed is opposite to that seen at the lower pole, suggesting that the upper and lower poles move in opposite directions, somewhat analagous to the movement of a see-saw. This hypothesis is confirmed by the attachment of a third accelerometer to a point around the middle of the patella, a position we have termed the "mode." At this position, a minimal signal is observed. Simultaneous traces from the upper pole, the node and the lower pole in flexion and extension are shown in Figure 4. At angular velocities greater than five degrees per second PPC is not observed. It is also not recorded during slow active knee movement, as at such slow angular velocities the movement is inevitably jerky and the angular velocity may often approach zero (Fig. 5). Following isometric loading of the patello-femoral joint the amplitude of the crepitus signal is greatly increased (Fig. 6).

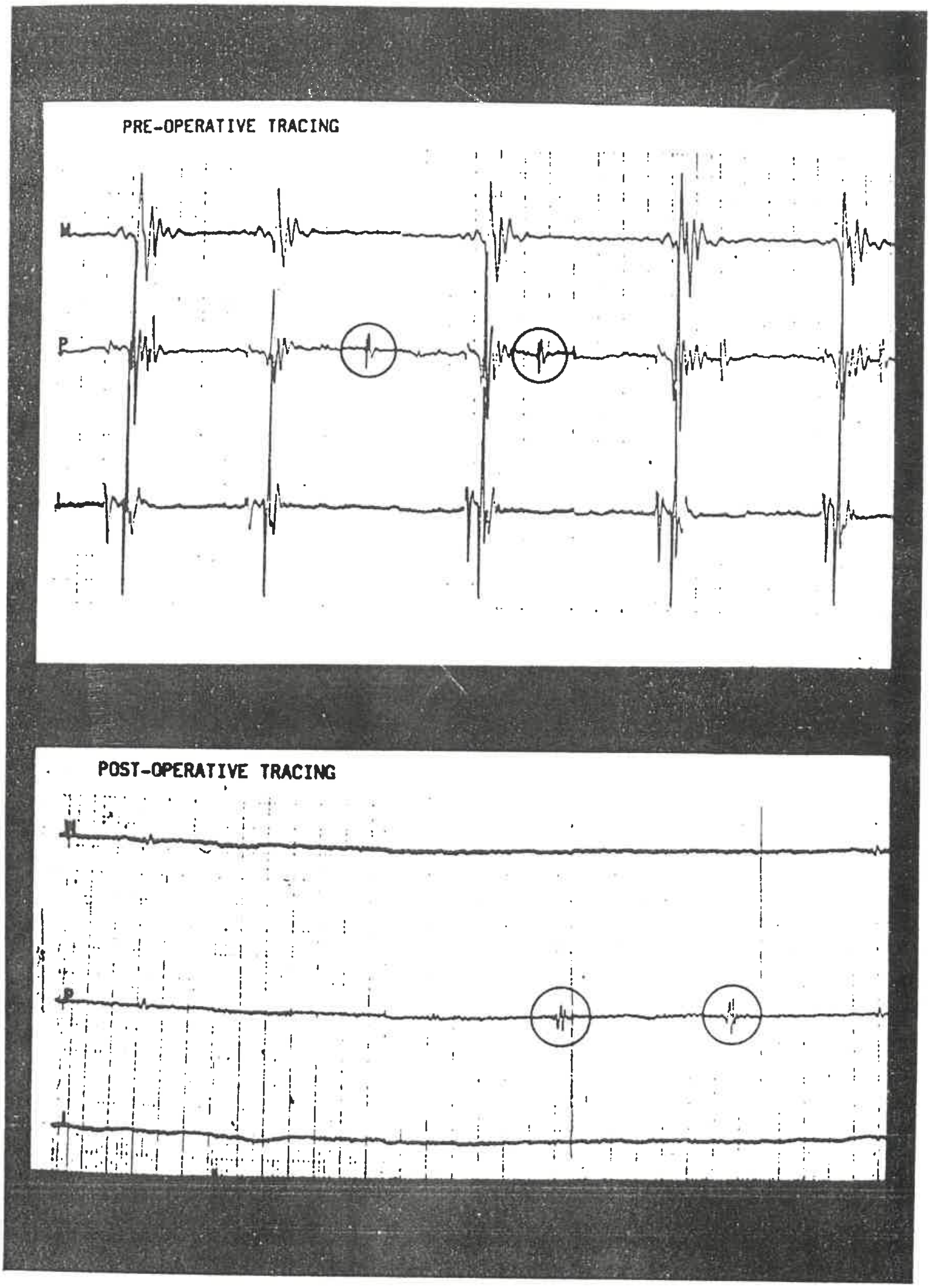

FIG. 3

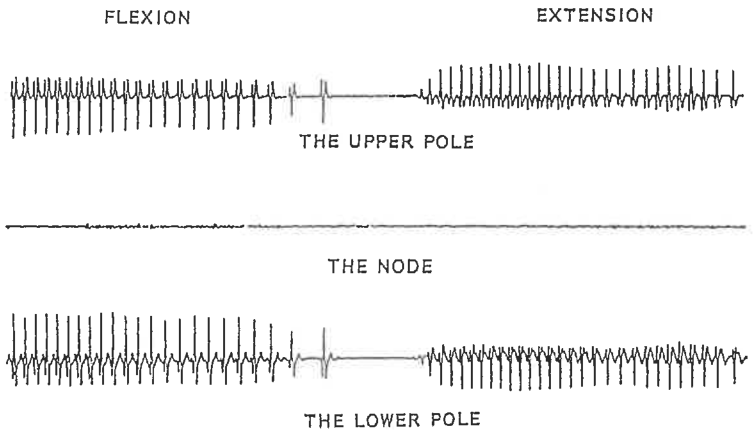

FIG. 4

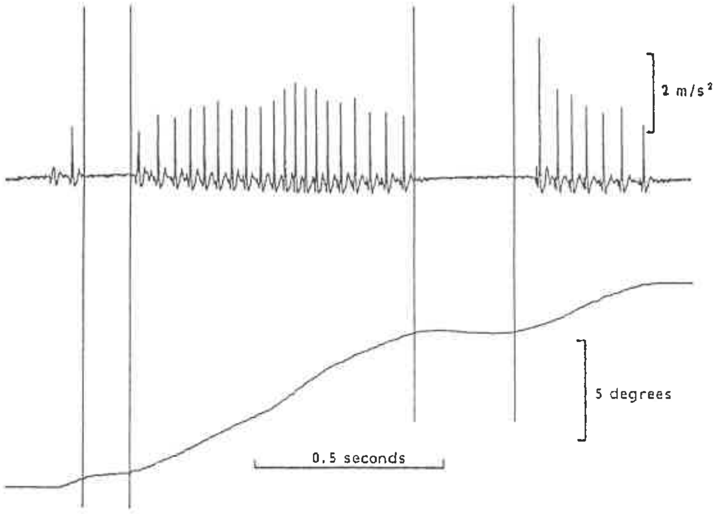

FIG. 5

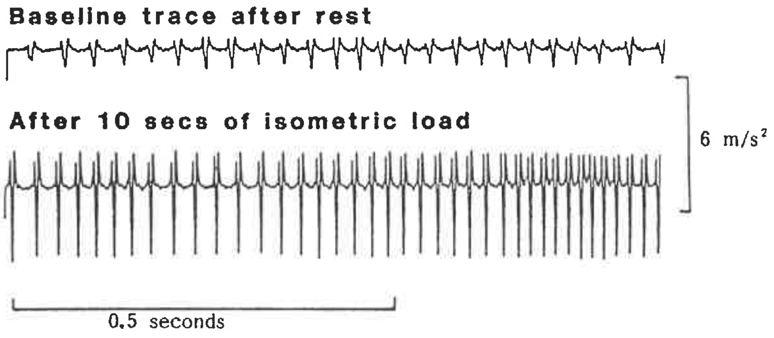

FIG. 6

DISCUSSION

Vibration arthrography represents an exciting development in the non-invasive diagnosis of knee joint problem. The diagnostic accuracy rate for meniscal injuries was 86%, significantly better than the generally accepted rate for clinical evaluation alone, and similar to the rates claimed for arthrography (2). In all cases the signal lateralised to the correct side and different types of meniscol lesion produced characteristic signals. We believe the meniscal signal to be the result of a sudden return to normal tracking resultant upon an alteration of the normal "roll-glide" as the result of mechanical obstruction. This concurs with the work of Frankel et al (3) which ascribes mechanical locking of the knee in meniscal injuries to such an alteration in roll-glide.

The effect of surgery on the meniscal signal was seen to be very significant. The majority of those patients reviewed had complete resolution of their symptoms in association with complete disappearance of the signal. Others displayed considerable diminution of the signal in the post-operative tracing. These meniscal signals represent abnormal energy imparted to the articular surfaces, as a result maltracking, by dislocatable lesions of the menisci. As such, the amount of energy detected directly parallels the potential for further cartilage damage. Menisectomy is therefore seen to reduce and, in most cases, abolish this potential for continuing cartilege damage. Moreover, vibration arthrography is seen to be an objective assessment of the efficacy of arthroscopic menisectomy.

The recording and subsequent analysis of PPC represents an objective measure of the state of the articular cartilage. Our evidence demonstrates that physiological patello-femoral creptius is a manifestation of stick-slip friction. The signal of PPC is observed in all normal knees. In advanced degenerative disease of the patello-femoral joint the signal is not seen. Many workers, such as Dawson, have shown that in vitro under static loads cartilage undergoes creep deformation. Concominant with this deformation there is a rise in friction i.e. as cartilage deforms its coefficient of friction rises. We have been able to demonstrate this phenomenon *in vivo* by recording a baseline trace of PPC and then loading the knee isometrically for ten seconds. Following loading the PPC signal is of greatly increased amplitude (Fig 6).

The clinical implications of these findings are exciting but require further evaluaton. At one end of the spectrum, a patient who has lost all articular cartilage due to degenerate disease produces no signal. At the other end a subject with normal articular cartilage not only produces a signal but will also exhibit an increase in amplitude of signal after isometric load as a result of cartilage deformation. Work is now continuing to control the production of PPC. This has involved the custom design and production of an apparatus to hold the lower limb securely and to move the limb at a range of predetermined and constant angular velocities. It is well known that as the knee moves through its range of motion the band of contact on its articular surface is continually changing in the manner described by Goodfellow (4). Pathological conditions such as chondromalacia patellae affect localised areas of the articular surfaces of the patella. It is suggested that, with controlled angular velocity, as the band of contact sweeps over the affected area, a change in PPC signal characteristics will appear. Vibration arthrography will therefore permit us, for the first time, to evaluate non-invasively the integrity of the articular cartilage.

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List of Illustrations

FIGURE 1: Tracing recorded from a subject with a complete (Type I) tear of the medial meniscus.

FIGURE 2: With a true posterior horn tear, the patella signal is often very small.

FIGURE 3: Pre- and post-operative tracings of a patient with complete resolution of symptoms following arthroscopic menisectomy. Note that the meniscal signal has also disappeared completely but the small "marker" signal seen over the patella persists.

FIGURE 4: Simultaneous recording from three accelerometers attached to the patella as labelled.

FIGURE 5: Many of the gaps observed in crepitus tracings are not produced by alterations in lubrication but by short periods of zero angular velocity.

FIGURE 6: Isometric loading greatly increases the amplitude of the PPC signal.