Editorials

The development of three-dimensional range of motion measurement systems for clinical practice

Evaluating the range and patterns of movement is a key concern for a clinician in the diagnostic and functional assessment of patients with musculoskeletal disease. These range-of-motion (ROM) measures are also used to obtain a record of the degree of permanent impairment of an individual [1–2].

Currently, clinicians use all or any of visual estimation, a universal goniometer, an inclinometer or a tape measure to make these assessments. However, these tools have major drawbacks in measuring ROM. The first concerns reliability. Patients are followed over a long period of time for many diseases, particularly chronic diseases such as ankylosing spondylitis [3]. It is important, therefore, that clinicians can be satisfied that any change in ROM over this period of time is real change in the patient and is not due to the measuring instrumentation or process. Furthermore, if a ROM measurement tool is not reliable, it is unlikely to be a valid measure [4]. Questions remain over whether these traditional ROM measurement tools have actually been tested rigorously for reliability. The evidence from a systematic review for cervical spine ROM demonstrates that either these tools lack reliability or their reliability is unproven, studies purporting to assess their reliability often containing major flaws in design or analysis [5]. This review also revealed surprisingly wide variation in the protocols for movement and measurement in research, and these are likely to be reflected in clinical practice.

Another drawback of these tools is that they only measure static range of movement. That is, the subject performs the required movement (for example, rotation of the cervical spine to the right) then holds the final position whilst the measurement of that movement is taken. The relationship between these two-dimensional assessments of movement and function of the musculoskeletal system is difficult to ascertain. Dynamic movement, including combinations of movements and the velocity of movement, is not captured and so a complete picture of the movement is not obtained. This may be particularly important in the movement of a complex joint, like the shoulder joint, where movement is three-dimensional.

Recently, three-dimensional measuring tools such as the ISOTRAK, ISOTRAK II and the FASTRAK (all from Polhemus, Colchester, Vermont, USA) have also started to appear in the literature [18–19].

The FASTRAK is a system that uses a dynamic method to measure ROM. It has the potential to measure the velocity of movement, movement in planes other than the primary plane of movement, and to measure secondary or substituted movements of the body elsewhere; hence it can build up the components of a movement. Electromagnetic fields generated from a source transmitter are used to determine the position and orientation of one or more remote sensors placed on the relevant parts of the body, and the data are updated many times a second. Measurements from the three different planes of movement (e.g. sagittal, frontal and transverse) are read into a computer and can be displayed as a trace (graph) with degrees of movement plotted against time (Fig. 1), or in the form of raw data. The FASTRAK system is shown in Fig. 2. For example, to measure cervical spine movement, one sensor is fixed on the forehead to measure the cervical spine ROM, and one on the sternum to measure secondary trunk movement.

The ISOTRAK II, by comparison, allows the use of only two sensors compared with the four allowed by the FASTRAK (although up to eight FASTRAK systems can be multiplexed). The FASTRAK can track sensors up to a distance of 10 feet away as opposed to 5 feet for the ISOTRAK II. The FASTRAK also has better latency than the ISOTRAK II [20]. Latency can be defined as the time that elapses between the movement and the updating of the display on the computer screen.

The surge in publications indicates the interest surrounding these new technologies. Their advent is providing an opportunity to assess movement in a more meaningful way. As the electrocardiogram revolutionized assessment of the heart, the use of FASTRAK and similar systems may well provide that elusive gold standard to assess the ROM of the musculoskeletal system. However, research into these systems can become haphazard, with no clear direction. Furthermore, there is a danger that, in the eagerness to make full use of their three-dimensional measuring properties, the assessment of the fundamental properties of these tools is ignored.

The measurements of ROM from these systems depend entirely on the software written to capture the data and the way the angles are calculated. If the results are to be reported as Euler angles (aligned with the conventional flexion–extension, abduction–adduction
and internal–external rotation axes of the joint in neutral, the calculated angles during movement will be dependent on the Euler angle calculation sequence (for the ISOTRAK this is azimuth, elevation and roll). It is therefore important to report, or standardize, both the calculation sequence and the orientation of the sensor to allow comparison of results between different systems and setups [21–22].

Standardized protocols for movement and measurement need to be established for different joints. The introduction of new technology may even lead the way in standardizing protocols for movement and measurement for more traditional techniques. Standardized and practical ways of fixing the sensors to the body still have to be found. We use Velcro straps or double-sided tape in measuring cervical spine and shoulder ROM, although one subject we measured was allergic to the tape used. The wires do occasionally tangle, this being a particular problem as the number of sensors used increases. One subject said she felt a little restricted by the wires and there is little doubt that a wireless version of the FASTRAK would be easier to use. It would also probably make subjects feel more comfortable. However, wireless versions are more expensive. One subject did comment that fixation of the sensors did make her think of performing the movements ‘properly’.

The reliability of these systems needs to be ascertained. The reliability of the FASTRAK on the cervical spine and shoulder in an asymptomatic population [17] and in ankylosing spondylitis [23] looks encouraging. However, the reliability now needs to be established for other joints and in symptomatic populations before these systems can find a place in clinical practice or in clinical research.

If the aim is to use systems such as the FASTRAK in clinical decision-making, then this technology has to gain clinical acceptability. Clinician enthusiasm is a

![Diagram of FASTRAK trace of cervical spine ROM. Three measurements each of flexion and extension, lateral flexion right and left and rotation right and left. The mean secondary movement shown is rotation during lateral flexion.](image-url)
vital ingredient in successfully installing new health technology in practice [24]. Clinicians need to be able to understand the FASTRAK and the output from the FASTRAK before they begin to use it in clinical settings. Therefore, clinicians should be brought in at an early stage to comment and make suggestions on the research agenda. The analysis of human movement is a fascinating and complex problem. In common with a number of clinical areas, for example, in the output of a spirometer in chest medicine, diagnosis and prognosis depend on the interpretation of traces like that shown in Fig. 1. One of the challenges in using the FASTRAK and related technologies is in interpreting the traces and assessing whether they make clinical and anatomical sense.

The FASTRAK needs to be seen to be cost-effective rather than as just an expensive toy. The inexpensive tape measure and goniometer can be slipped into the pocket and taken easily from room to room; the FASTRAK is less portable and needs to be set up and connected to a computer, and it is therefore more time-consuming to set up and to use. Windows-driven, user-friendly software can be developed to make operation easy even for computer-wary clinicians. An alternative may be to send patients elsewhere to be measured by the FASTRAK (saving the clinician time), just like sending a patient to be X-rayed. The link to the computer has major advantages as it means that measurements for a patient can be stored straight on to the computer and displayed on occasions of further assessment to see if any change has occurred. Longitudinal assessment, therefore, will be much easier. Also, graphs of ‘normal’ movement and typical traces of ROM (if they exist) for a number of illnesses and injuries which affect ROM could be stored and displayed on the screen at the click of a mouse to ease diagnosis.

These three-dimensional measuring systems cannot replace a clinician’s professional experience, particularly in evaluating quality of movement. For example, it will not fully detail the ease and smoothness of movement or pain during movement, although subjects could indicate with a press of a button the point at which the movement becomes painful. This could be linked to the computer to enhance the information gathered by the trace. The FASTRAK should, therefore, be seen as a part rather than constituting the whole of the movement analysis package. However, the FASTRAK can give a more complete picture of movement than traditional tools and provides a permanent record of movement. If diagnostic patterns of movement can eventually be established, for example, for rotator cuff injury, then it will add objectivity to clinical judgement, which is important from the perspectives of both clinical risk and outcomes. This more objective measure of movement may also be welcomed in medicolegal cases, for example.

Most clinicians (and, certainly, patients) are more interested in functional movement than the classical anatomical movements along the lines of the maximum ROM of flexion/extension, lateral flexion and rotation. For example, Rowe et al. [25] assessed how much knee motion is needed in the elderly for common functional activities such as walking and sitting down. The FASTRAK and similar systems may also have the potential to assess the three-dimensional movement in functional activities, and to detail movement more accurately. Burnett et al. [26] used the FASTRAK to assess three-dimensional lumbar movement in cricket fast bowlers. Measuring functional movement is an area for future research.

The FASTRAK also has potential applications in clinical research. For example, Woodburn et al. [27] are detailing the accuracy, precision and repeatability of the kinematics of the lower limb (including ankle joint). One of their goals is to validate the FASTRAK for use as an outcome measure in randomized controlled trials of therapeutic interventions in the treatment of the rheumatoid foot.

Furthermore, it can be an aid in educating the patient, and even in educating clinicians about movement in both asymptomatic and symptomatic populations. Patients may understand more easily how their movement is limited and how it improves or deteriorates over time by reference to the traces and comparison with ‘normal’ traces.

Other systems have been touted for use in human motion analysis, and they have their place, particularly in clinical research. Cameras tracking markers placed on the body and linked to a PC have long been used in research, particularly for gait analysis. However, unlike the FASTRAK with its sensors, it is possible for the camera(s) to lose track of the markers or for the markers to cause confusion by crossing each other’s paths.

The problems of installing new health technologies in clinical practice have been well documented [24]. One of the prime factors is the enthusiasm of clinicians, whilst local circumstances can also affect whether new technologies are accepted [24]. In North Staffordshire, clinicians have been involved in the early research on the FASTRAK. The enthusiasm for the system here, therefore, may be greater than in areas where no research has been performed on three-dimensional measurement systems. Effective dissemination of research findings...
is important; the evidence needs to be strong and the research well-structured. We need high-quality communication between researchers on advances in research and methods, and some way of identifying a way forward for a programme of research on three-dimensional motion analysis systems.

All the potential applications listed here for these new technologies are some way into the future. Establishing protocols for movement and measurement, assessing validity and reliability and understanding the traces and data must be the initial aims. Then we can begin to use the FASTRAK as a diagnostic tool, as an outcome measure or to assess the range and type of movement needed for different activities. New technologies like the FASTRAK will allow more objective measurement of movement and could provide a framework for defining diagnoses and outcomes, and for longitudinal assessment. Currently, the FASTRAK and similar systems can be said to have potential; only when their development has reached a clinically useful phase will they have a place in the multidimensional assessment of health outcomes.


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