Current methods for cervical spine movement evaluation: A review

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ABSTRACT

Cervical spine mobility is difficult to investigate accurately because of its anatomic structure and the compensatory movements. Different methods have been conceived in order to obtain a reliable measurement of cervical range of movement (ROM). We reviewed different instruments described in the literature: x-rays, CT and MRI, goniometer, inclinometer, cybex and related devices, and opto-electronic scanners.

Cybex and 3D kinematic analysis by means of opto-electronic scanners (Elite system) seemed to be the most reliable and reproducible methods. Cybex equipment is relatively inexpensive and easy to use in a clinical setting, while the Elite system is expensive and requires special training of the personnel. However, the choice of method depends primarily on whether the physician's goal is a clinical screening or a thorough investigation of neck function (e.g., post-traumatic cervical spine disorders). For the first purpose, certain types of goniometers (gravity goniometer, ad modum Myrin), as well as the cybex, show good reproducibility and reliability in evaluating maximal cervical ROM (flexion-extension, rotation, lateral bending), while x-rays and, above all, 3D kinematic analysis (using opto-electronic scanners) are more suitable for diagnostic and follow-up evaluation of neck disorders.

Anatomical findings

Motion in the cervical spine is actually divided between two anatomic units, the occipito-atlanto-axial complex and the unit extending from the 2nd cervical vertebra (C2) through the first thoracic vertebra (T1). Most authors use the terms "upper cervical spine" to describe the occiput - C2 and "lower cervical spine" to describe the C3-T1 region. Data collected in previous years on range of motion (ROM) of the cervical spine were based on plain radiograms, cineradiograms, stereoradiograms and cadaveric studies. Regarding the upper cervical spine, the atlanto-occipital joints permit only flexion-extension motions with no significant lateral flexion or rotation, while the atlantoaxial joints allow flexion, extension, rotation and at least measurable lateral gliding motions (1-2). Previous studies have shown that the occipito-atlanto-axial complex permits a total flexion-extension average of 23°, the occiput-atlas joint having a mean ROM of 13° in flexion-extension and the atlantoaxial joint an average ROM of 10° in flexion-extension. Contrarily, rotation occurring only at the atlantoaxial joints, coupled with translation, is approximately of 47°. The extremely firm attachment of the lateral masses of the atlas to the occipital condyles prevents rotation at the atlanto-occipital joint.

At the lower cervical spine, all four of the classic spinal motions occur between the C3 and T1 vertebrae, i.e. flexion, extension, lateral flexion and rotation (1-2). Flexion does not occur as an isolated motion, but may be associated with accompanying rotation (100-110°). This is due to the increasingly caudally oblique contours of the articular surfaces. In the flexion-extension movement there is more motion in the central region, as the C5-C6 interspace is considered to have the greatest range of motion in the sagittal plane joint. Moving lower down the spine, lateral flexion and rotation range of motion progressively diminish. In lateral flexion (30-40°) the lower articular surfaces on the concave side glide downward and backward, while on the convex side they glide upward and forward, resulting in lateral flexion coupled with rotation of the joint. Since ≈50% of the rotation occurs at the atlantoaxial joint, the same event occurs, but to a lesser extent, in rotation (35-40°). In addition, axial rotation is always coupled with lateral bending of varying magnitude.

Discs seem to be maximally deformed by extreme lateral and forward flexion, while the disc spaces widen posteriorly and narrow anteriorly, also sliding forward perceptibly.

Challenge in evaluating neck movement

Clinical challenge

It is generally agreed that it is difficult to accurately measure cervical spine mobility. This low accuracy in the assessment of cervical ROM is due to the few available landmarks and the depth of the soft tissues overlying the bony segments.

There are also numerous compensations that take place during different movements so that the clinical evaluation of cervical spine mobility clearly becomes insufficient. Moreover, mobility is thought to be influenced by aging, biomechanical factors and pathologic developments (3), i.e.: 1) the amplitude of lateral flexion varies greatly from one subject to another and is reduced by age and pathology without great discomfort; 2) on the contrary, reduction in the amplitude of rotation is soon felt as a major inconvenience in daily life, especially by car drivers (however, there is an almost linear correlation between lateral flexion and rotation); 3) at the same time, the amplitude of flexion-extension movement is preserved for decades, although there may be functional disorders (such as feelings of dizziness, tinnitus, photopsias) caused by assuming certain positions and/or performing certain movements, probably due to the close neurovascular interactions that take place in this area.

Instrumental challenge

It must be noted, however, that cervical spine movements are too often assessed on purely clinical grounds, that is, by measuring the distances between the chin and the manubrium sterni and between the occiput and the spinous process of T1.

From a technical point of view, many instruments described in the literature are unwieldly for the operator and cumbersome for the patient, affecting the latter's willingness to move and the reliability of the measurement. More recent methods seem to be more acceptable and reasonably reliable, but still involve "mounted headgear". In recent years many advances have been made in the three-dimensional study of neck movements.

Current methods

Several methods and instruments have been described in the literature, many of them designed to investigate post-traumatic cervical spine disorders. The diverse techniques used to define cervical spine mobility reflect the difficulty of accurate assessment. The ideal method, of course, is a technique that is neither too invasive nor too complex to perform in a practical manner, and that provides data from which it is possible to extrapolate parameters that are clinically useful and appropriate. The following summary discusses the characteristics of different techniques, including their reliability, reproducibility, and pros and cons.

Clinical evaluation

A subjective, qualitative observation of the range and path of motion is routinely performed by clinicians to analyse passive and active neck movements. A tape measure has also been used to quantify cervical ROM, as indicated in the study of Alaranta *et al*. (4), or a metric ruler with masking tape and a high-backed wooden chair, as described in the study of Hanten *et al*. (5) in order to measure resting head posture (both standing and sitting) and total head excursion.

To measure resting head posture while standing, a metric ruler is extended from the wall perpendicularly to the reference point, while subjects are asked to assume a relaxed, natural posture. To evaluate the patient when sitting, the chair is placed at a fixed distance from the wall and the end of the ruler is positioned so that it extends from the wall at a 90° angle, approaching close to the subject's left zygomatic arch. The sitting, resting head posture is obtained by touching each subject's mark with a pencil point and extending the pencil perpendicularly to find the corresponding point on the ruler. Furthermore, after having practiced the full movement, subjects are asked to flex and extend as far as possible, while their scapulae and hip are still touching the chair back. The respective points are marked on the ruler. This method is clinically practical, as it can provide objective, quantitative measurements of the total head excursion and the resting head posture quickly and with minimal equipment.

X-ray

The kinematic function of the cervical spine can be examined by means of cineradiography or a sequence of lateral x-rays, usually of a flexion-extension range of motion. One of the major problems in the interpretation of these studies is how to extract information from the x-ray images which are reliable and also diagnostically useful. Another problem is the rising amount of radiation involved as one increases the number of steps of motion between full extension and full flexion in order to obtain a more detailed examination.

Dimnet *et al*. (6) carried out one x-ray for each of 5 neck positions (full flexion, full extension, and 3 intermediate positions) during voluntary flexion-extension motion, thus obtaining a balance between x-ray exposure and ROM parameters. From each set of x-rays, different parameters were derived for both a kinematic (angles and centres of rotation) and a geometric (pattern of curvature) description. The position (location and orientation) of each vertebra was determined on each x-ray, transforming all the coordinates from the global system of the digitizer (33 x 33 cm, connected to a PDP 11/34 computer) to a local 3-axes system fixed on C7 for each x-ray (because C7 may move with respect to the x-ray machine during the test). Subsequently, the kinematic and geometric ("mean curvature") evaluation of the movement are derived separately. In a previous study (Dimnet,1978), this technique displayed a superior reproducibility and fewer errors than those found in other radiological techniques. It also showed a good correlation with clinical information and the contracted/condensed/elaborated results in patients with known structural abnormalities (Table I).

The Arlen method (3), a simple, reliable and reproducible method designed to analyse intervertebral dysfunctions, has been used since 1960. It consists of measuring the mobility of each cervical vertebra in relation to the overlying vertebra by taking lateral x-rays, first at rest, and then in maximal flexion and maximal extension. Subsequently, a simple calculation can be made by a pocket calculator of the differences between the intervertebral angles at rest and during

Table I. X-ray techniques for the evaluation of cervical spine mobility.

Author	Technique	Study population	Parameters obtained	Reliability and reproducibility	Advangages	Disadvantages
Dimnet *et al.* (6)	One lateral-view X-ray for each of 5 neck movements (full extension, flexion and 3 intermediate positions)	12 subjects: 6 young and healthy + 6 patients	Kinematic (angles and centres of rotation) and geometric (pattern of curvature) data	Acceptable reproducibility (checked in a previous study)	Good agreement between clinical information and x-ray results for the 6 pts.	Radiation exposure, expense, time required, complex geometric reconstruction
Kraemer & Patris (3)	Arlen method	699 normal subjects aged 12 to 87 yrs (F/M: 416/283)	Difference between interverte-bral angles at rest and during flexion & extension; total mobility of the spine (total flexion, total extension and global mobility)	Good reproducibility	Reliable, reproducible, easy to carry out after a period of training, capable of identifying and locating functional abnormalities	Radiation exposure, the bulk of the data, the need of an examiner trained in performing the calculations
Amevo *et al.* (7)	Flexion-extension radio-graph with the patient wearing a goniometer helmet	109 pts. (M/F: 3/4), aged 33.8 ± 8.6 yrs., with uncomplicated neck pain	Instantaneous axes of rotation (IAR)	Acceptable accuracy suffi-cient for diagnostic purposes, quantified in a previous study	An objective marker for the presence of pain (useful in medico-legal proceedings)	Lack of segmental specificity so that it lacks immediate and diagnostic value
Dvoràk *et al.* (8)	Flexion/extension radiographs	64 adults (F/M: 45/19), aged 22 to 58 yrs, with functional disorders of the cervical spine	Segment motion parameters such as rotation, translation, centers of rotation, and translation/rotation ratio	Good reproducibility and reliability (checked in previous studies)	A computerized method useful to follow up changes in cervical motion patterns (e.g., after an operation), helpful in diagnosing and locating neck disorders	Radiological exposure, expensive

Table II. Different goniometers for the evaluation of cervical spine movement.

Author	Type of goniometer	Study population	Cervical mobility investigated	Reliability and reproducibility	Advangages	Disadvantages
Kasir *et al.* (12)	"Liquid" goniometer (with glass tube containing 50/50 alcohol/water +2% fluores cent dye to act as spirit level	10 volunteers	Full range of horizontal rotation, flexion-extension & lateral flexion	Intra- and inter-observer reliabi-lity within acceptable ranges (except for horizontal rotation)	Simple, accurate, quick, inexpensive, useful in comparative clinical trials	Examiner experience can enhance the reproducibility
Podolski *et al.* (13)	Hand-held goniometer	25 healthy volunteers age 18-57 (mean 34)	Flexion, extension, rotation and lateral bending while lying supine	?	Non-invasive, easy to use, inexpensive	?
Tucci *et al.* (14)	Gravity goniometer with spirit level and head adapter versus universal goniometer	10 volunteers	Maximal range of flexion-extension, rotation and lateral bending	Higher reliability of the gravity goniometer, even with an untrained examiner	Simple, quick, easily constructed, inexpensive and reliable	?
Eklund *et al.* (15)	Electric goniometer measurement system	16 work vehicle drivers (fork lift trucks, cranes, etc.)	Maximal voluntary movement (MVM) in the 3 planes (flexion, extension, rotation, lateral bending)	Validated by a previous study (16)	Long-term battery supply, inexpensive to maintain, easy to apply on the body, with no mechanical restriction	Bulky, possible difficulties in positioning the rods correctly at the anatomic reference points of the head or neck
Hagen *et al* (17)	Goniometer ad modum Myrin	49 forest machine operators	Flexion-extension, lateral flexion and axial rotation	Good reproducibility	Easy to use, reliable	?

flexion and extension. The total mobility of the cervical spine is evaluated by adding the single intervertebral values, obtaining values for the total flexion, total extension and global mobility. This method can accurately locate pathologies which may disturb the spinal dynamics, sometimes even before clinical signs appear, and thus is useful in the follow-up and treatment of patients with such pathologies.
In a more recent study (7), Amevo *et al.* focused attention on the quality of movement of each segment, which they defined according to the location of its instantaneous axes of rotation (IAR). IAR is obtained by connecting the corresponding points of each vertebra in its two positions (flexion/extension), after superimposing the tracings of the lower vertebra in any motion segment, thus revealing displacement undergone by the upper vertebra. Then the perpendicular bisectors of these intervals are constructed and the point of intersection of these bisectors is recorded as the IAR. Having verified its reliability and accuracy and established a normal range of IARs for the cervical spine, the authors found that an abnormal IAR does correlate with the presence of pain, even if this parameter is not related to the segmental source of pain.
A further tool for the evaluation of flexion-extension radiographs was developed by Dvoràk *et al.* (8), in which segmental motion parameters such as rotation, translation, centres of rotation and the translation/rotation ratio are calculated using a computer program. It has been demonstrated that individual patterns and statistically significant differences exist between patients and the healthy population, an aspect that can be used in clinical assessment. Lateral x-rays are taken at full extension and flexion induced by the examiner. Then the computer program mathematically superimposes the vertebrae using positional data from the digitizer and calculates specific motion parameters (Table I).

CT and MRI

CT and MRI techniques are difficult to use for clinical range of motion evaluations. In particular, CT range of motion studies are a complex undertaking (requiring the use of sophisticated reconstruction algorithms), suitable only for research, while MRI images require the subject to be motionless for long periods of time. Moreover, MRI is difficult to interpret due to many variations in the process, although unlike CT it may not require contrast enhancement to obtain a better resolution between tissues.

Goniometer

Goniometers are devices designed to measure the relative rotation of a given joint. The simplest form is a single axis potentiometer with two arms connected to the long axes of two adjacent body segments. As the two body segments rotate, the output resistance of the potentiometer changes, leading to the measurement of rotation. Clearly, the goniometer's centre of rotation must match the joint's centre of rotation in order to obtain a valid measurement. Since movement in human joints is usually characterized by more than a single degree of freedom, multiple degree of freedom devices have been developed. In 1949 Moore (11) described such a device, a universal goniometer consisting of a double stationary arm extending from both sides along the 0 to 180° line of the protractor, and one movable arm.
Recently, instruments with a serial attachment of single-axis potentiometers interconnected by small, rigid links have been developed, which can actually measure all six degrees of freedom. Such devices require a calibration procedure in order to relate the output of the individual potentiometers to either an inertial or a body-centered anatomical reference system. Although studies have demonstrated the accuracy of this type of goniometer, it has some practical limitations that have prevented it from gaining widespread acceptance in clinical studies. The main shortcomings are the following: 1) the need for additional information in order to obtain the joint loads, since it is impossible to incorporate the measurements directly into the dynamic equations of the multi-link system; 2) the presence of a mechanical constraint, represented by the tight attachment of the goniometer across the joint, which limits the motion of the soft tissues and thereby modifies the natural motion of the joint; 3) the cumbersome (and sometimes heavy) nature of the goniometric apparatus; 4) the non-linear effects that are inherent in a mechanical linkage system, such as stick-slip and backlash problems; and 5) the need to develop specific transducers for different joints.
Using a "liquid" goniometer, Kadir (12) found an inter-observer difference of 1.6% or less, while a significant difference was found for rotation. The intra-individual difference in an experienced observer ranged between ±7° and ±13°, while in the non-experienced observer it was between ±10° and ±15° (Table II). This apparatus was demonstrated to be useful in evaluating the results of a comparative clinical trial, adding objective measurements to purely subjective assessments of pain.
In a later study, Podolsky *et al.* (13) tested a hand-held goniometer and found that it produced reliable results for the assessment of the efficacy of cervical immobilization methods.
In a study carried out by Tucci and coworkers (14), the reliability of a standard gravity goniometer with spirit level and head adapter was compared to that of a universal goniometer, by determining the correlation coefficients for both an experienced and an untrained examiner. A high degree of inter-rater reliabiltiy was found (ICC range 0.80-0.91) even with the inexperienced examiner.
A more complex technique, using an electric goniometer measuring system with a mechanical form of transmission between the head and the upper trunk, was tested in the study of Eklund *et al.* (15). The apparatus consists of 3 main parts: a harness, a headband, and a mechanical transmission between the harness and the headband. The maximal range of voluntary movements was determined using reference values for the head and trunk, with the patient standing upright and looking directly forward, after individuating a neutral biomechanical position, and performing maximal voluntary movements in the three planes. These procedures were repeated at the beginning and at the end of each session. The signals from the equipment were recorded first on a tape recorder, then played back, and the signals were recorded

on paper, both for general monitoring and for a detailed visual evaluation of the temporal pattern. The authors applied a two-dimensional analysis, plotting each sample point in a two-dimensional diagram, in which clusters of points represent common postures taken.

One disadvantage of Eklund's device is the difficulty of using it in a public environment because of the highly visible rods and headband, while an advantage is the long-term battery supply and its inexpensive maintenance, added to the fact that it is easy to use and involves no mechanical restrictions. According to the authors (15, 16) this method has also a good reproducibility.

In a more recent study (17), the maximal cervical ROM was recorded with a "Myrin" goniometer (Lic Rehab AB, Linkoping, Sweden), which measured flexion-extension and lateral flexion by means of a pointer controlled by gravity and axial rotation with a compass. The ROM between the neutral position and maximum angular displacement of the head was recorded. Three consecutive movements in each direction were performed, after which the median value was used as the ultimate value. The authors claim that this method can, to a large extent, discriminate between the presence and absence of subjective neck pain, even when clinically the differences in cervical mobility between individuals with and without pain appear to be marginal.

Thus, ROM tests may be useful tools to describe impairment and constitute a basis for the assessment of therapeutic interventions. The reproducibility of the ROM measurements proved to be good, with an estimated standard deviation for replicated measurements by the same examiner of the same individual of 2.8° (lateral flexion left) to 4.3° (lateral flexion right) (Table II).

Inclinometer

Inclinometers use another technique based on direct body-place transducers. In a study by Moffet *et al.* (18) the reliability of the inclinometer was thoroughly tested. Flexion, extension and side flexion were measured with the subject seated facing a mirror. For the flexion-extension movement, the inclinometer was placed on a Velcro band, firmly fixed around the head above the eyebrows and just above the ear, the zero being lined up with the tragus. In the side flexion measurement, the inclinometer was placed at the back of the head, with the zero lined up with the spinous process of C7. Rotation was measured in the supine position with the Velcro band repositioned and attached under the chin. Each movement was repeated twice and the best two readings were recorded. Statistical analysis of the data showed no difference in either the intra-observer or between-observer measurements. Despite the reliability shown by the statistical analysis, it was not possible to produce repeated measurements for each movement with less than about 15° discrepancy for the same observer, or 20° in the case of extension. This inter-individual variability seems to depend on many variables, including subjective factors such as discomfort, pain and motivation, and indicates that a single change of less than 15° in the ROM should not be interpreted as evidence of worsening or improvement (Table III).

More successful results were reported by Alaranta *et al.* (4), who evaluated the reliability of spinal flexibility measurements made by means of inclinometers and tape measures. They used a liquid inclinometer (MIE, Medical Research Ltd, London, UK) for cervical flexion-extension and lateral bending and a gravity inclinometer (Pendulum goniometer, McDesign Ltd, London GB) for cervical rotation. The inter-observer reliability of the 2 methods proved to be acceptable (reliability factor (r) values ranged between 0.69 and 0.86), while the intra-observer reproducibility was less than acceptable. Flexion-extension and side bending movements were significantly reduced among those symptomatic subjects reporting disabling pain in the neck.

Cybex and other devices

In the study by Highland *et al.* (19) a cervical extension machine (MedX Corp., Ocala, FL) was used to assess extensor strength, ROM and strength training in a group of patients with different cervical spine abnormalities (degenerative disc, herniated disc and cervical strain). His apparatus showed good reproducibility in measuring changes in strength and ROM during flexion-extension in patients with non-spinal cord injuries of the cervical spine (Table IV).

Other clinical tools have been devised to evaluate cervical mobility such as the functional axial rotation (FAR) instrument of Schenkman *et al.* (20), which consists of a flat metal band secured by rivets to create a hoop 1 meter in diameter, with symbols (numbers and letters) placed at 5-degree intervals around the inner ring. It was designed to measure the rotation of the head and thorax in relation to the pelvis, and visual performance during this movement. The limitation of this device is that it monitors the capacity for movement without determining the causes of any such limitation (e.g., pain or joint or soft tissue restriction). The inter-observer and test-retest reliability were good (ICC = 0.97 and ICC = 0.90 - 0.95, respectively).

Zwart (21) in a recent study used a Cybex instrument (EDI-320) to assess neck mobility in different headache disorders (cervicogenic, migraine, tension-type headache) compared with controls. The author evaluated flexion-extension, rotation and lateral bending, performing 3 measurements for each movement and using the mean for statistical analysis. A highly significant correlation was found between active and passive neck movement both in controls and patients. Repeated investigations showed a high intraclass correlation coefficient (ICC: flexion-extension 0.78; lateral bending 0.69; rotation 0.94). The equipment is non-invasive, relatively inexpensive, and easy to use in a clinical setting.

3D kinematic analysis: Opto-electronic scanners

Many different opto-electronic devices have been designed to carry out non-invasive, three-dimensional dynamic measurements of neck mobility (Table V).

Berger *et al.* (22) developed a method to measure 6-axis movement (Cervicomotography), by means of an electronic instrument which is useful for the investigation of segmental and multi-segmental motional disorders of the neck.

Roozmon *et al.* (23) tested the Cervicoscope, a recent variation of the Spinescope, an instrument that uses 3 cameras

Table III. Inclinometers to measure cervical spine movements.

Author	Type of inclinometer	Study population	Cervical ROM investigated	Reliability and reproducibility	Advangages	Disadvantages
Moffet *et al.* (18)	Inclinometer	34 healthy female subjects (14 students)	Flexion-extension, side flexion and rotation	Good inter- and intra-observer reproducibility	Simple, quick, inexpensive	15° resolution
Alaranta *et al.* (4)	Liquid and gravity inclinometer	508 male and female white- and blue-collar workers aged 35 to 54 yrs	Flexion-extension, rotation and sidebending (the mean of left and right movements as the final result)	Good inter-observer reliability for both methods	Easy to use, inexpensive, quick, sufficiently accurate	Intra-observer reliability unacceptably low; not a good tool for follow-up measurements over a long period of time

Table IV. Cybex and other devices to assess cervical spine mobility.

Author	Technique	Study population	Parameters obtained	Reliability and reproducibility	Advangages	Disadvantages
Highland *et al.* (19)	MedX Cervical Extension Machine	90 pts. with non-spinal cord injuries (6 degenerative disc, 14 herniated disc, 70 cervical strain)	Flexion-extension, extensor strength and strength training	?	Safe, non-invasive	Only flexion-extension evaluation; torso restraint and shoulder harness, although useful, can limit ROM
Schenkman *et al.* (20)	Functional axial rotation (FAR) device	9 M and 6 F, aged 20-74 yrs	Rotation of the head and thoax relative to the pelvis, and visual performance	Good intra- and inter-observer reliability (ICC: 0.90 - 0.95 and 0.97, respectively)	Easy to construct and use, non-invasive	Reflects capability of movement without considering the causes of limitation (e.g., pain, etc.)
Zwart (21)	Cybex equipment	88 headache patients + 51 controls	Rotation, flexion-extension and lateral bending	Good inter-observer reproducibility, acceptable reliability	Reliable, reproducible, non-invasive, easy to use in a clinical setting	Lateral bending evaluation

Table V. Three-dimensional kinematic analysis: opto-electronic scanners.

Author	Technique	Study population	Parameters obtained	Reliability and reproducibility	Advangages	Disadvantages
Roozmon *et al.* (1991)	Cervicoscope, using three cameras to track a series of infrared emitting diodes	? (Review article)	Cervical lordosis, thoracic kyphosis and intresegmental mobility	?	Non-invasive	Unable to identify coupled joint motion, expensive
Roozmon *et al.* (1992)	Cervicoscope with an improved set of displays	1 normal subject	Vector normal to the head, neck, and thoracic spine, angles of vectors with respect to the absolute reference frame	?	Non-invasive, accurate (precision of deduced angles: 1°)	Sophisticated software techniques, expensive, requires tests of reproduciblity
Ferrario *et al.* (1997)	Digital image analyser for detection of single markers coupled with algorithms, by 3-D facial morphometry	30 healthy subjects	Instantaneous centre of rotation and curvature radius during flexion-extension movements	?	Allows unrestricted movements, no modifications of head position	Does not separate the contributions of the atlanto-occipital and cervical spine joints, expensive
Bulgheroni *et al.* (1998)	3-D computerized kinematic analysis by means of an opto-electronic motion analyser (Elite System)	8 healthy subjects	Flexion-extension, rotation and lateral bending (expressed in degrees)	High inter-observer reliability	Non-invasive, reliable, easy to use, useful in the diagnosis of whiplash injury and headache stemming from from the neck	Expensive, training of personnel required

Table VI. Angle setting for the implementation of 3D kinematic analysis by the Elite System.

Movement	Angle setting	Plane	Evaluation
Flexion	C7-EOP	Sagittal	Cervical spine movement
	EOP-LH	Sagittal	Head movement in relation to neck movement
Extension	EOP -LH	Sagittal	Head movement versus neck movement
Rotation	LH-RH	Horizontal	Head rotation
Lateral bending	C7-EOP	Frontal	Cervical spine movement
	EOP-LH	Frontal	Head movement in relation to neck movement

to track a series of infra-red emitting diodes (IREDs) placed on the lower back, shoulder and pelvis. The cervicoscope, developed specifically to analyse cervical motion, monitors 7 markers located between vertebrae C2 and T3; two more placed at T4 and T7, as well as four above the iliac crests and scapulae. This version was found to have shortcomings in its ability to quantify simultaneous motion in different directions. In a further study therefore (24), this device was improved by adding a display describing coupled joint motion. The authors used a series of plots illustrating principal movements, including flexion-extension, lateral bending, and axial rotation versus secondary movements. The coupled motion software is based on the movement of vectors calculated from the 3D spatial co-ordinates of IREDs placed on the head, neck, and shoulders, developing 3 algorithms to deduce the relative direction angles between vectors normal to the different groups of IREDs and with respect to the absolute reference frame. This analysis of mobility was expected to be valuable in differentiating between normal and pathological movements of the cervical spine. Unfortunately, sophisticated software engineering techniques are required to efficiently and accurately present the required information to the users of this diagnostic device.

Another complex method to analyse 3D head kinematics is the one applied by Osterbauer *et al.* (25), based on the employment of a helmet with a reflective marker and top-mounted laser pointer placed firmly on the subject's head. The subject sits in a variable height, adjustable chair facing a wall with vertical, horizontal and oblique target lines. Markers are also mounted on a rigid plate that is securely fastened on the back to allow the monitoring of any back movement, with a marker taped over the spinous process of T1 as an anatomical reference to the output. Flexion-extension and oblique movements are recorded by asking the subjects to trace a line on the wall with the laser (asking them to look down at the base of the wall (-50°) and to begin looking upward at a comfortable pace until they reach +50°, and then returning to -50°, and to trace the oblique lines from the upper right to lower left and then back, and then from the upper left to the lower right and back). Raw data are acquired and 3D coordinates calculated using the Motion Analysis Expert Vision system. Three of the parameters investigated have been proposed as useful for characterizing the Instantaneous Helical Axis, a mathematical description of the three-dimensional movement between irregularly shaped objects, in our case the head with respect to the torso.

In a more recent study Ferrario *et al.* (26) used a digital image analyser (ELITE, BTS, Milan, Italy) developed for the detection of single markers coupled with algorithms formulated at LAFAS (Ferrigno and Pedotti, 1985; Frigo 1990). The system is able to perform the real time detection of wireless, stroboscopically illuminated retro-reflective markers by means of two high-resolution infrared-sensitive CCD video cameras with electronic shutters. Head movement was detected using a 3-D facial morphometry method, calculating the instantaneous centre of rotation (ICR) and radius curvature for each flexion-extension movement and subject. This motion analyser is useful to quantify alterations in the pattern of movement in patients with cervical disorders and can supply useful information regarding the pattern of motion, providing insight into vertebral kinematics.

Another three-dimensional kinematic

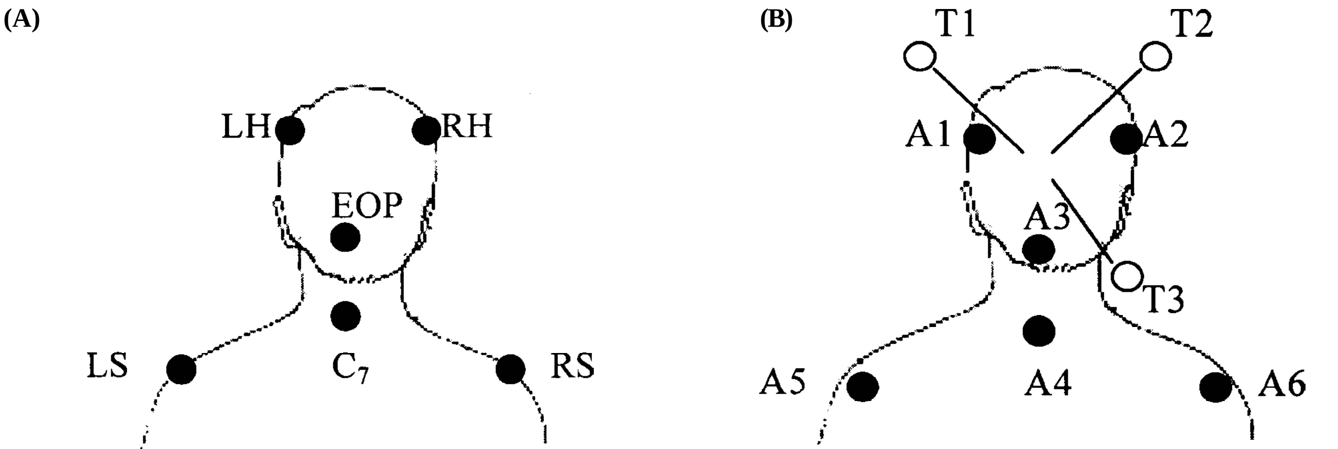
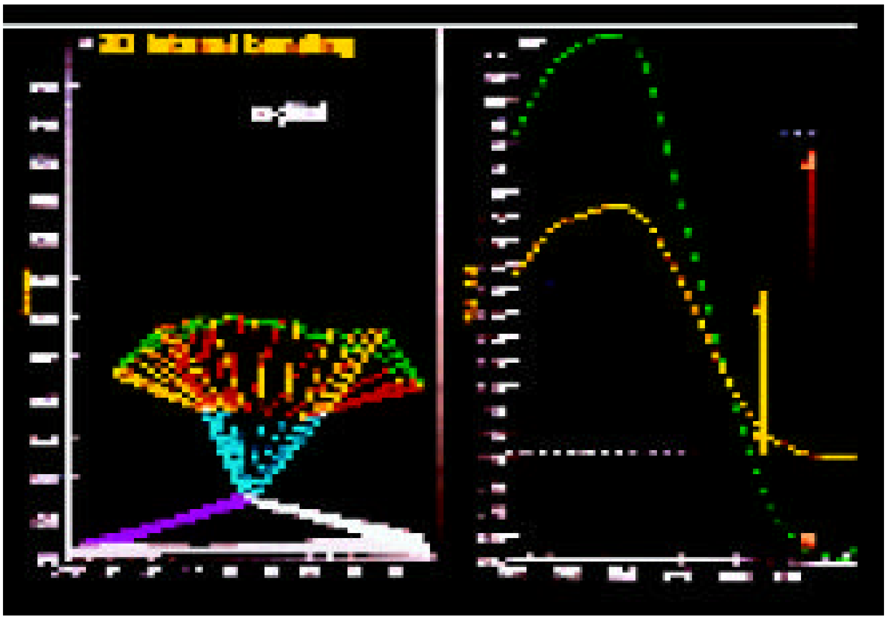


Fig. 1. (A) Basic marker set-up on head and trunk while the subject is still. The markers are as follows: (LH) left and (RH) right sides of the head (located 4 cm apart on either side of the head vertex), (EOP) external occipital protuberance, (C7) seventh cervical vertebra, left shoulder (LS) and right shoulder (RS) on the acromion protuberance. (**B**) Technical markers (T1 to T3) and anatomical markers (A1 to A6) during the anatomical calibration procedure.



(**A**) (**B**)

Fig. 2. Three-dimentional computerized measurement of cervical movement (lateral bending) in a healthy subject using the ELITE system. (**A**) cervical movement (C7 - EOP), x axis = degrees, y axis = mm; (**B**) head movement in relation to neck movement (LH - RH), right side: x axis = mm, y axis = degrees.

method to evaluate neck movement was developed by Bulgheroni *et al.* (27), based on passive markers and 2 infrared TV cameras (ELITE System, BTS, Milan, Italy) working at a sampling rate of 50 Hz. The ELITE system is an opto-electronic motion analyser able to carry out the real time detection of passive marker coordinates inside the field of each TV camera. The kinematic model designed requires the reconstruction of 6 anatomical points, 3 of them describing the head and the other 3 describing the trunk (Fig. 1A). Because of the wide ROM, direct acquisition of markers positioned over the selected anatomical points is not always possible. Thus, it is useful to acquire markers which are more easily visualised during the performance of the movement ("technical markers"), by means of "anatomical calibration", an acquisition trial designed to capture the geometrical relationship between anatomical points and technical markers (Fig. 1B). The angle setting (Table VI) is developed on the basis of the angle between the head coordinate system and the laboratory coordinate system, because of the fixed position of the trunk. This method is statistically reliable (inter-observer reliability: ICC = 0.83-0.92; ICC = 0.74 for extension) and is able to supply a complete description of head/neck mobility (Fig. 2).

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