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by Penelope B Butler
Richard E Major

The Missing Link?

Therapy issues of open and closed chains

Summary This paper explores the use of the terms 'open kinetic chain' and 'closed kinetic chain' and the neuromuscular control implications of maintaining either the open or the closed chain. An understanding of the underlying biomechanical concept is crucial to correct interpretation of whether the kinetic chain is open or closed. However, a historical review of the origins of the terminology in mechanical and bio-engineering literature reveals a variety of interpretations and thus proposals are made of ways in which the terminology might be standardised by the introduction of two new terms.

Examples of identification of control strategies and deficiencies are given and the value of this knowledge in planning appropriate treatment strategies is discussed.

Finally, current assessment tests and procedures are reviewed, discussing the issues of open and closed chains.

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Introduction

The terms 'open kinetic chain' and 'closed kinetic chain' have become increasingly common in rehabilitation although their meaning is rarely precisely defined. From an engineering perspective, the human skeletal structure can be considered as a collection of articulated rigid links with movement generators spanning the articulations. It is generally agreed that an open kinetic chain is consistently present where the end terminal is free of constraint, such as the head during walking. For therapists with an interest in control issues, the implication of an open unsupported chain is that there is enough neuromuscular control at all articulations for the subject to adopt an open chain strategy successfully. However, what precisely is meant by 'closed kinetic chain' is less clear since authors vary in their descriptions. If a closed kinetic chain is observed, then the subject may, or may not, have a control deficiency or weakness in one or more of the closed chain joints. Careful assessment will be required to clarify the situation and thus any necessary therapy strategies needed to address the impairment. A clearer understanding of the issues involved is the subject of this paper.

Historical Review

It is helpful to look back at some of the origins of the terminology in mechanical engineering to be aware of the varied interpretations in their application to the human structure. An early discussion of related issues was produced by Franz Reuleaux (1829-1905) and published in serial form between 1871 and 1874 with an English translation made by Kennedy in 1876 (Reuleaux, 1963). Reuleaux proposed the concept of the 'closed kinematic chain' in which every alteration in the position of a link relative to the next results in a defined and predictable alteration in the position of every other link relative to the first. Constructing a chain from three interconnected bars forms a rigid structure with a fixed geometry. This falls outside Reuleaux's definition since no relative movement is possible (fig 1a). The four-bar chain is the only simple two-dimensional mechanical system composed of rigid articulated links that fulfils the criteria. Illustrations of such a chain appear, in various guises, throughout Reuleaux's development of ideas on machine design.

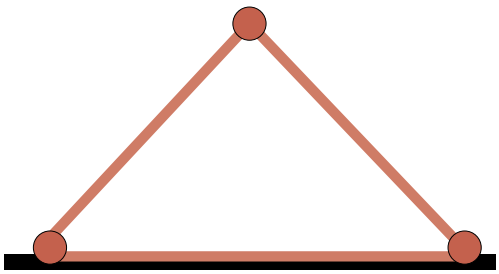

Fig 1a: This simple three-element closed chain is locked in the position shown. No movement is possible and thus no control is required

Authors

Penelope Butler PhD MCSP is director of the Movement Centre at the Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS Trust, Oswestry.

Richard E Major BSc IPEM is head of Bioengineering in the Regional Medical Physics Department, Newcastle General Hospital.

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Address for Correspondence

Dr P B Butler, Director, The Movement Centre, Robert Jones and Agnes Hunt Orthopaedic and District Hospital NHS Trust, Oswestry, Shropshire SY10 7AG.

However, the definition also implies that at least one articulation must be under active control, although the control status of the remaining joints need not be defined and it may not be possible to determine, by observation, which is the controlled articulation (fig 1b).

The addition of a fifth bar leads to a mechanism that can take up a variety of geometries, two of which are shown in figure 1c (caption 1). Increasing the number of segments, as may be necessary when considering the human skeletal structure, extends the number of possible geometries.

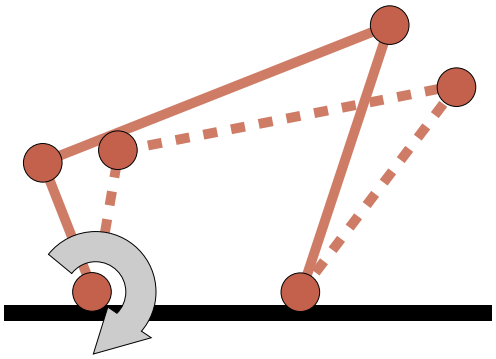

Fig 1b: In the four-bar closed kinetic chain shown, moving through small angles, a control input at any one of the four joints is enough to describe fully the resultant motion. However, if motion is observed it is impossible to know which, or how many, joints are under active control

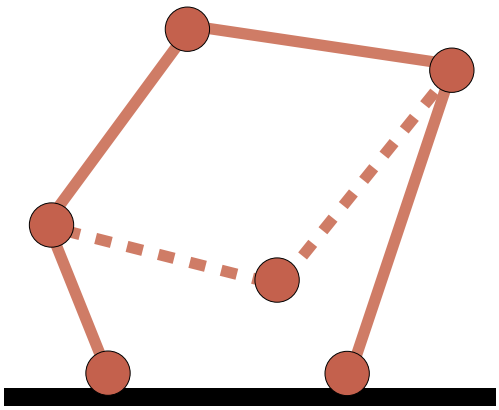

Fig1c: 1. Extending the number of bars beyond four removes the possibility of uniquely defining the configuration of the closed kinetic chain. In this example the solid or dashed geometries are both possible

2. Ensuring that a particular option is taken up will need additional control to be exercised at one additional joint

3. The concept can be extended revealing that each time a new link is added, control at one additional joint must also be added to assure a particular geometric option. Thus the rule may be derived that for an *n* link closed chain (*n*–3) nodes must be under active control for assured geometry

Various authors developed this concept of mechanical chains in terms of biomechanics in succeeding years, adhering to the original definition to a greater or lesser extent. Dempster (1955), while studying ergonomic issues for the United States of America Air Force, concluded that the human structure was an open chain system although a number of closed kinematic chains, such as that exhibited by the ribcage, were identified. Steindler (1955) considered that when one limb met 'an overwhelming resistive force' then muscle action changed and he described this as a 'closed kinetic chain' – a concept that was used by Gowitzke and Milner (1988) in their example of an individual standing and pushing against a wall. Steindler further developed his argument stating that: 'In the standing body the lower extremity is a closed kinetic chain, ie a system of articulations joined to an external resistance.' This proposal had the widest use and subsequently any weight-bearing situation was described as a closed chain (Russek, 1996; Lehmann, 1992).

A variety of therapy strategies have since evolved that advocate both the 'open' and 'closed' kinetic chains (Fitzgerald, 1997). These regimes often use exercise ergometers, which are also finding popularity in the management of neurological disorders (Potempa *et al*, 1995).

Terminology Development

A number of important steps have been made to allow concepts that were originally developed to aid machine design to help in the study of the human musculoskeletal system. The full implication of these steps must be appreciated in order to analyse the clinical situation correctly.

Gowitzke and Milner recognised that when part of the human body makes contact with a fixed object then reaction forces are likely to be present. These forces restrain the body from passing into the space occupied by the object and, provided frictional forces are high enough, prevent sliding along the surface. Thus a new form of semi-constrained connection has been recognised going beyond that envisaged by Reuleaux. However, the body remains able to move

away from the object and any resulting closed chain may be transitory.

Steindler, however, took a chain which Reuleaux would have considered to be open and called it a 'closed kinetic chain'. The justification for the term 'closed' was simply on the grounds of an external force being present and this created a bifurcation of terminology between those using Reuleaux's approach and that now advocated by Steindler. The reason for using the term 'kinetic' as opposed to the original 'kinematic' is unclear but might reflect the recognition that control through muscle action introduces the need to include forces within any analysis.

It is worth noting that Steindler, in the same volume, introduced his analysis of the upright articulated human structure with the statement: 'As each link rests upon the one underneath it, the connecting articulation is the supporting surface bearing it.' It is a simple step to realise that as analysis of the supporting surface moves down through the upright human structure, more and more mass has to be supported. Thus his observed changes in muscle activity could be the response to supporting and controlling a large mass rather than a true change in chain status.

The concepts of open and closed kinetic chain exercise have been developed particularly in the field of sports science (Lutz *et al*, 1993; Augustsson *et al*, 1998; Wilk *et al*, 1996). In this situation, the closed kinetic chain exercise is usually described as having the terminal or distal segment of a limb fixed, such as during a squat, leg press or pull-up, while open kinetic chain exercise allows free movement of the distal segment, such as during knee extension or flexion. However, closer analysis reveals that these exercises do not have common starting positions in relation to gravity. The closed kinetic chain exercise of the squat, for example, is performed with the subject standing while the closed kinetic chain leg press exercise is performed with the subject lying supine (Wilk *et al*, 1996). Those undertaking such exercise are most often fit healthy sportspeople where considerations of possible impaired control of trunk muscles are unlikely to be an issue. A full analysis about the presence or absence of control can, however, be made only when the chain is not externally supported.

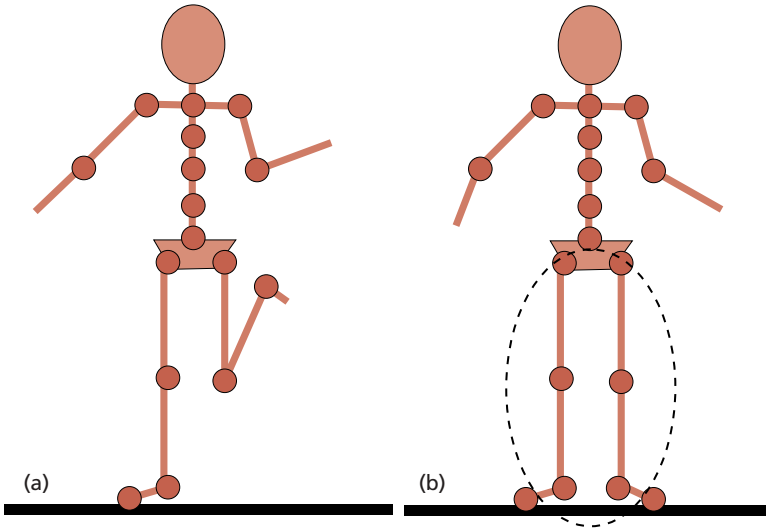

Fig 2: (a) During single stance the human skeletal system comprises open chains provided that both upper limbs are free. Defined movement is reliant on full control of all joints

(b) Double stance represents a combination of open and closed chains (shown enclosed by hatched ring)

Does it Matter?

Jones (1997) suggested that the inappropriate use of terminology threatened the scientific credibility of therapists. However, the present authors propose that if the concepts can be used to gain analytical insight into the strategy used by a patient in producing a particular posture or movement, then they are likely to be of therapeutic value beyond any considerations of credibility. Careful definition of the terms will be critical to ensure correct analysis.

The concepts can be explored by analysis of normal walking. During the swing phase of gait only one foot is in contact with the ground and thus, according to Reuleaux's definition, all body segments comprise open chains (fig 2a). During double stance, when both feet are simultaneously in contact with the ground, a closed chain exists comprising the pelvis, all lower limb segments and the ground (fig 2b) but this chain has too many segments to be a 'closed kinematic chain' as proposed by Reuleaux (fig 1c, caption 2).

Proposed Revised Terminology

The introduction of the terms 'controlled closed kinetic chain' (CCKC) and 'controlled open kinetic chain' (COKC) could help resolve some of the difficulties that have emerged and allow clinicians and researchers to demonstrate that they have considered the underlying issues.

A controlled closed kinetic chain is

proposed as a system of links that form a closed loop, permanently or for a short period of time, where a maximum of three of the articulations between links need not be under active control. Examination of any controlled closed kinetic chain reveals that, for a closed chain comprising n links and articulations, active control at n–3 articulations can produce the required conditions of defined and predictable motion of every link as required by Reuleaux (fig 1c, caption 3).

In a controlled open kinetic chain it is implicit that all articulations are under active control at all times and, although not a requirement, only one part of the chain may be in contact with a support surface. Developing Steindler's concept of level of support, the definitions may be applied either to the whole or to part of the body.

Aid to Understanding Motor Control

These definitions are of value to therapists only if they aid understanding of patients' problems and help to guide intervention. As suggested above, the presence or absence of a controlled open kinetic chain can help clarify the existence of active control strategies. An open chain will be maintained without collapse only if neuromuscular control can resist the moments acting about all joints. Joint position can be maintained passively if a joint is at a bony or ligament end stop.

Adequate muscle strength will be a component of this open chain control together with the ability to invoke muscle activity as required to meet movement goals. However, a patient may be able to adopt a controlled closed kinetic chain position and thus appear to control a particular joint by exercising control through other joints in the chain. It is then no longer possible to infer the control status of any one particular joint in the closed chain. Although the patient may have achieved the specific functional goal, control difficulties at one or more joints in the closed chain may preclude other movement objectives, thus limiting functional variability.

In the foregoing discussion it is recognised that some simplification has been made in the development of these proposals. A full analysis of active neuromuscular control at a joint or joints should include gravitational and inertial considerations, the visco-elastic properties of ligaments and other soft tissue together with proprioceptive and other feedback mechanisms. However, while mechanical chain analysis can give insight into the presence or absence of control, these additional factors are outside the scope of this paper. A further limitation of this approach to understanding control issues is that only visual observations are used in making an analysis, but this also represents an advantage in terms of clinical applicability.

Detection of the controlled closed

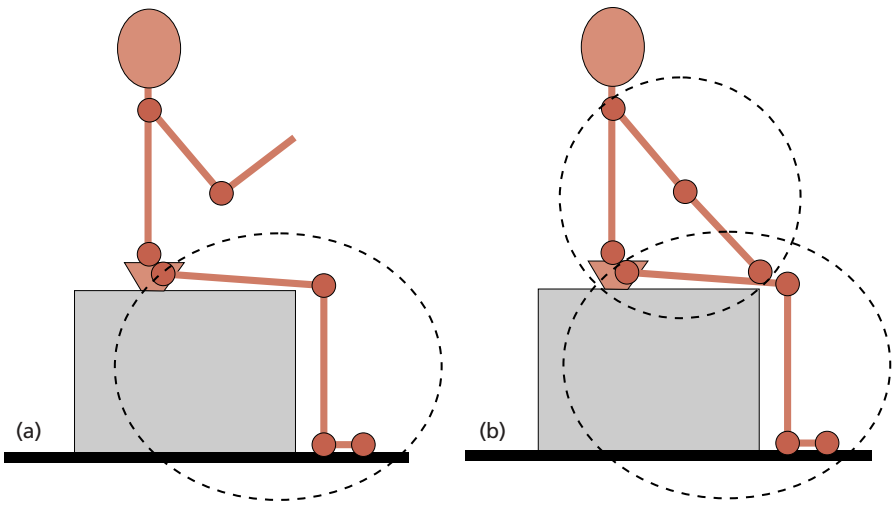

Fig 3: (a) Open chains are present above the pelvis if the subject is sitting erect without hand or back support; the spinal column will be under full neuromuscular control as long as the joints of the spine are not at the end of range. The pelvis, lower limb segments, floor and seat constitute a closed chain (b) Cross bracing of the arms to the thighs or to the seat surface means that the spinal column forms part of a new independent closed chain from the neck downwards and introduces uncertainty about control of spinal segments

kinetic chain is not always as straightforward as identification of the controlled open kinetic chain. The posture of the trunk in sitting provides an example. If patients sit fully erect with thighs and feet supported but with no back support then it can be inferred that all joints of the trunk are under active neuromuscular control as long as the arms are free of all contact with either the support surface or the body – the trunk chain is open. As soon as the patients rest their arms on their thighs or on the support surface then the trunk chain, excluding the cervical spine above the shoulder girdle, is closed and the arms provide cross bracing over the joints of the trunk. An upright posture can be maintained in this manner but may be compensatory for impaired control at one or more joints of the trunk (fig 3a, b).

A subtler compensatory manoeuvre is collapse of the lumbar spine into full flexion, often with rearward rotation of the pelvis. The overall sitting posture may be near erect and the hands may not be providing support. However, the lumbar joints then form a semi-closed chain with the flexible elements – the posterior ligaments – fully extended in tension, obviating the need for active neuromuscular control. Thus in this sitution, an observer cannot know if the posture is maintained through neuromuscular control or by mechanical means.

Assessment of Motor Control

The majority of functional assessment tests do not help in identification of open and closed chains. If trunk control and sitting posture are again taken as an example, a review of commonly available assessment methods reveals reflection of overall function rather than specific detail. Molnar and Gordon's (1976) predictive signs for early prognostication of motor function in cerebral palsy simply used the term 'sitting' with no description or definition of trunk posture or use of hand support; while Beals (1966), in his prognostic indicators for walking, used a loose definition of 'sits alone for five to ten minutes'. Thus, in either of these two assessments, a child might sit with or without hand support and with or without collapse of spinal segments. Although the child might be able to maintain a stable position, the posture might not indicate future likely achievements on the basis of inherent active neuromuscular control.

Other more detailed tests fare little better. The Gross Motor Function Measure (Russell *et al*, 1993) does not define trunk posture necessary to achieve a score even though it describes various sitting postures. For example: 'Sitting on a bench: maintains, arms and feet free, 10 seconds. Place the child on a large bench (ie feet dangling unsupported). If stable sitting is achieved ask the child to lift the arms to the "arms free" position'. This could be achieved using a slumped trunk posture with lumbar collapse.

Illustrations accompanying the levels of sitting ability defined by Green and coworkers (1995) show both open and closed chain examples in support of one defined postural level. The Sitting Assessment for Children with a Neuromotor Dysfunction (Reid, 1995; Reid *et al*, 1996) is divided into two sections, passive and active sitting. Although the requisite trunk posture is illustrated, both sections of the assessment require that at least one hand is resting on the child's thigh throughout.

Confusion also exists in tests used with adults, such as the Motor Assessment Scale (Carr *et al*, 1985) where grade 2 'balanced sitting' is defined as 'sits unsupported, turns head and trunk to look behind. Have hands rest on thighs' and the top grade (5) as 'sits unsupported, reaches forward to touch floor and return to starting position. Support affected arm if necessary.'

Care is also needed in non-standardised assessment, such as review of video recordings, if inferences are to be made about control status. A boy with muscular dystrophy might walk with his hands resting on thighs. Rather than being a simple preferred posture, even light hand contact may highlight inadequate neuromuscular control around the hips and the need for assisted manual stabilisation.

Conclusion

Issues of closed and open chains are particularly pertinent when considering the neuromuscular control status of joints and enable a distinction to be made between joints clearly exhibiting active control and those which may have control deficiencies. Active control can be inferred only if the chain is open and any possibility of surrogate control is

Key Messages

- The terms 'open kinetic chain' and 'closed kinetic chain' have become increasingly common in rehabilitation but are rarely precisely defined.
- The terms 'controlled closed kinetic chain' (CCKC) and 'controlled open kinetic chain' (COKC) are proposed.
- The neuromuscular control implications of maintaining either the open or the closed chain can be very different.
- Compensatory strategies for inadequate neuromuscular control may not be identified if the concepts of the open and closed kinetic chain are not fully understood.
- Many of the assessment tests and procedures in common use do not take account of these issues.
- It is only when joint control status has been established, through correct recognition of an open or a closed chain, that therapy strategies can be put in place to address any control deficiencies.

eliminated. Two new terms, the 'controlled closed kinetic chain' and the 'controlled open kinetic chain', could focus attention on these issues and thus help clinicians to identify control status. It is only when joint control status has been established that therapy strategies can be developed for addressing any control deficiency.

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