Pelvic Kinematic Method for Determining Vertical Jump Height

Loren Z.F. Chiu and George J. Salem

Sacral marker and pelvis reconstruction methods have been proposed to approximate total body center of mass during relatively low intensity gait and hopping tasks, but not during a maximum effort vertical jumping task. In this study, center of mass displacement was calculated using the pelvic kinematic method and compared with center of mass displacement using the ground-reaction force-impulse method, in experienced athletes (n = 13) performing restricted countermovement vertical jumps. Maximal vertical jumps were performed in a biomechanics laboratory, with data collected using an 8-camera motion analysis system and two force platforms. The pelvis center of mass was reconstructed from retro-reflective markers placed on the pelvis. Jump height was determined from the peak height of the pelvis center of mass minus the standing height. Strong linear relationships were observed between the pelvic kinematic and impulse methods (R² = .86; p < .01). The pelvic kinematic method underestimated jump height versus the impulse method, however, the difference was small (CV = 4.34%). This investigation demonstrates concurrent validity for the pelvic kinematic method to determine vertical jump height.

Keywords: 3D motion analysis; biomechanical methods; concurrent validity

Jumping requires explosive force generation by the lower limb extensors, and is a common test of lower extremity power (Bosco & Komi, 1979). Numerous methodologies exist for estimating vertical jump height. The most common field test is a jump and reach test (Patterson & Peterson, 2004). In a biomechanics laboratory, both kinematic and kinetic methods have been used. Kinetic methods involve a force platform, where displacement is estimated from ground-reaction force impulse (Bosco & Komi, 1979; Harman et al., 1991; Kibele, 1998). Kinematic methods determine total body center of mass via link-segment modeling from video (Harman et al., 1991). Video and force platform methods give similar estimates (Komi & Bosco, 1978). Modern motion analysis systems, however, use optoelectronic cameras that record retro-reflective marker coordinates. This poses a problem, because unless markers are placed on each segment of the body, total body center of mass cannot be determined. While analyses of joint kinematics and kinetics are of value for studying intersegmental coordination, analyses of whole-body performance are also necessary. For example, joint kinematics and kinetics at the ankle, knee and hip do not scale linearly in the progression from submaximal to maximal jumping (Vanrenterghem et al., 2004). Thus, studies of intersegmental coordination should also consider whole-body performance (Flanagan & Salem, 2005; McNitt-Gray et al., 2006).

Two kinematic methods have been proposed for approximating total body center of mass motion without a whole-body marker set. These include tracking a single marker placed on the sacrum (Gard et al., 2004) and modeling the center of mass of the pelvis (Ranvolo et al., 2008; Saini et al., 1998; Whittle, 1997). Both methods assume that motion of the pelvis is representative of the total body center of mass. By approximating total body center of mass, researchers would be able to estimate parameters of whole-body performance, such as gait or running velocity, and vertical jump height using a lower extremity-only marker set. These methods have been evaluated during gait and hopping (Ranvolo et al., 2008; Saini et al., 1998), however, not for maximal vertical jumping. A field test using the same principle is used for jumping, where a measuring tape is attached to the pelvis and a pulley fixed to the ground (Slinde et al., 2008). The purpose of this investigation was to assess the validity of the pelvic kinematic method for vertical jump height.

Methods

Male athletes (n = 13) were recruited to participate in this investigation. Participants provided written informed consent as approved by the University of Southern California Health Sciences Institutional Review Board. The athletes competed in power sports (weightlifting, volleyball,
A six degree of freedom retro-reflective marker set was used, including calibration and tracking markers. Calibration markers were used to identify joint centers (distal foot—1st and 5th metatarsal heads; ankle—medial and lateral malleoli; knee—medial and lateral epicondyles; hip—greater trochanter) and tracking marker clusters to measure segment motion during dynamic trials. The hip joint center was modeled as 25% of the distance (medial to the greater trochanter markers) between the greater trochanters. Calibration markers were removed for dynamic trials. Five markers were placed on the pelvis—left and right anterior superior iliac spine, left and right iliac crest, and posterior sacrum (below the L5 spinous process). All markers were used to reconstruct the pelvis during a standing calibration trial; however, the anterior superior iliac spine markers were removed for dynamic trials.

Markers were recorded using an 8-camera optoelectronic motion analysis system (Vicon 612; Lake Forest, CA) collecting at 120 Hz. After the standing calibration trial, participants performed a brief warm-up of bodyweight squats and submaximal jumps. After the warm-up, participants performed 3 maximal effort vertical jumps with hands behind their head. Depth of the countermovement was not controlled. Participants rested between jumps ad libitum. Vertical jumps were performed standing on two force platforms (AMTI OR6–6; Watertown, MA), with ground-reaction forces sampled at 1560 Hz. Marker data were processed in Vicon Workstation (version 4.5) and exported to Visual 3D (version 3.13; C-Motion; Germantown, MD). Marker coordinates were filtered using a low-pass fourth order recursive Butterworth with a 6 Hz cut-off frequency.

Foot, shank and thigh segments were modeled from the cluster of tracking markers and the proximal and distal joint centers. The pelvis was modeled as a conical frustum and center of mass estimated based on segment geometry (Hanavan, 1964). The proximal end of the conical frustum was identified as the left and right iliac crest markers and the distal end as the left and right hip joint centers. The center of mass method is superior to a single sacral marker because with a single sacral marker, anterior or posterior pelvic tilt may raise or lower the marker without an actual change in center of mass elevation. Vertical jump height was determined by subtracting the height of the pelvis center of mass during quiet standing (with hands behind head) from the maximum height during the jump. As a criterion, jump height was determined using the impulse-momentum relation (Bosco & Komi, 1979; Kibele, 1998). Vertical ground-reaction force impulses were digitally filtered using a low-pass fourth order recursive Butterworth with a 40 Hz cut-off frequency. Body weight was determined over a 1 s quiet standing period and subtracted from the force-time curves. The concentric phase was identified when the knee joint switched from flexion to extension. Vertical ground-reaction force impulse was integrated using the trapezoid method from the start of the concentric phase until take-off. Impulse from the left and right force platform were calculated independently and summed. Take-off velocity was calculated from impulse divided by body mass, and jump height calculated using standard equations for motion (Kibele, 1998).

Reliability of jumping kinematic and kinetic parameters from between days trials has been established previously in our laboratory (ICC > 0.85; unpublished data). Simple linear regression was used to determine the relation between jump height using the pelvic kinematic and ground-reaction force impulse methods. Regression models were run for the best jump from each participant. The difference between methods was also determined using a paired samples t-test and coefficients of variation.

### Results

The regression model for the best jump from each participant indicated a strong linear relation between methods (Figure 1; \( R^2 = 0.86; \) \( SEE = 0.03; p < .001 \)). The t-test indicated a significant difference (\( p = .03 \)) between the pelvic kinematic (mean ± SD; 0.46 m ± 0.06) and ground-reaction force impulse (0.48 m ± 0.07) methods. The average coefficient of variation for the difference between methods, however, indicated the difference was small (CV = 4.34%).

### Discussion

This investigation demonstrates a strong linear relation between two methods for determining vertical jump height. Although a significant difference was found between the methods, the coefficient of variation was small (4.34%). Hatze (1998) reported within subject variability of 0.63–6.47% for vertical jumping, therefore the difference observed between methods falls within the
typical error for jumping. With few exceptions, the pelvic kinematic method underestimated jump height compared with the ground-reaction force impulse method. The small differences and linear relations indicate that the pelvic kinematic method is valid for determining vertical jump height.

To our knowledge, this is the first investigation to compare the pelvic kinematic method to a criterion (vertical ground-reaction force impulse) during maximal effort vertical jumps. The difference between kinematic and kinetic methods has been studied during rhythmic hopping (Ranvolo et al., 2008). Significant differences were observed between the kinematic and kinetic methods, however, it should be noted that center of mass excursion was evaluated and not jump height. When comparing the orientation of body segments during quiet standing and at the jump apex, there are few differences (i.e., ankles are likely to be plantar-flexed at the jump apex). If excursion of the total body center of mass is compared with excursion of the pelvis between these two positions, minimal differences should be expected, as we observed. However, if the excursion of the total body center of mass and pelvis during the countermovement are evaluated, differences are likely to be observed. As countermovement depth increases, the rotations of the trunk, thigh and shank segments do not increase linearly, thus, motion of the pelvis is not representative of the total body center of mass (Ranvolo et al., 2008).

Furthermore, in Ranvolo et al. (2008), the relations between the different methods were not studied. Although differences in magnitudes may be present between the two methods, a methodology will still demonstrate concurrent validity if the differences are consistent. In the current investigation concurrent validity was demonstrated between the pelvic kinematic method and the ground-reaction force method using linear regression techniques. The strong relation, low standard error of estimate and small coefficients of variation, indicate that the pelvic kinematic method can be used to determine vertical jump height during biomechanical investigations.

The pelvic kinematic method is particularly useful for motion analysis investigations where only lower-body marker sets are used. This experimental set-up is commonly used with modern optoelectronic motion capture systems. While these methods increase accuracy and ease of determining joint kinematics and kinetics, only segments that are instrumented with markers can be analyzed. While a large number of recent publications have investigated joint kinematics and kinetics during jumping and landing tasks, these works have largely ignored center of mass dynamics. Joint kinematics and kinetics do not scale linearly with center of mass dynamics during jumping (Vanrenterghem et al., 2004); therefore, it is important to study mechanics at both whole-body and segmental levels (Flanagan & Salem, 2005; McNitt-Gray et al. 2006). The pelvic kinematic method is representative of the center of mass for jump height, and can be determined simply using pelvic markers already employed in jumping research. A modified pelvic kinematic method may also simplify 2D video analyses of jumping, as the center of mass of the pelvis can be modeled more easily than the center of mass of the entire body.

Valid estimates of jump performance may be obtained using different methodologies; however, the magnitude of jump height differs between these methods (Markovic et al., 2004; Slinde et al., 2008). Previous comparisons of force platform methods, including ground-reaction force impulse and flight time methods, and video-based total body center of mass estimates have demonstrated similar magnitudes (Bosco & Komi, 1979; Komi & Bosco, 1978). The pelvic kinematic method used in this investigation generally underestimated jump height compared with ground-reaction force impulse, however, the difference was small. Abalakov’s test has been reported in two investigations to overestimate jump height compared with force platform methods (Markovic et al., 2004; Slinde et al., 2008). Abalakov’s test is similar to the pelvic kinematic method, in that the displacement of the pelvis (from a belt worn around the pelvis) is determined. Abalakov’s test assumes that the belt moves vertically in a linear fashion; however, nonlinear motions may increase the measured displacement, which may explain the different findings.

As different methods may yield concurrently valid data, interpretation of vertical jump performances must consider the method used to determine jump height. Jump and reach tests are perhaps the most common field tests, due to their ease and low equipment requirements; however, they overestimate jump height compared with force platform methods (Markovic et al., 2004). Thus, it is difficult to compare jumping performance between field and laboratory studies. As normative data on jumping performance is typically collected using jump and reach tests (Hoffman, 2006; Patterson & Peterson, 2004), it is not currently possible to compare jumping performance using laboratory-based measures to data from a larger population. It may be prudent to develop regression equations that allow comparison of vertical jump performance between different measurement methods.

In conclusion, the concurrent validity of the pelvis center of mass kinematic method of determining vertical jump height has been demonstrated in comparison with the vertical ground-reaction force-impulse method. This simple method may be applicable for investigators using optoelectronic motion analysis and lower extremity marker sets, to evaluate movement outcome and relate joint/segment mechanics. Similar methodologies have been studied in gait and hopping, and may be useful for investigating other movements.

References


