Review Article

LUNGEOMETRY- GEOMETRICAL INVESTIGATION OF LUNGE

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ABSTRACT

Physiotherapists must learn the biomechanics of lunge in detail to clearly understand its significance in human life and implement effective training measures to overcome the limiting factors of proper lunge of their clientele. To understand the biomechanical value of every movement, interesting experimental learning methods must be employed to kindle the Physiotherapists to actively take part in research activities from the under-graduate level onwards. Lungeometry is a novel, simple and inexpensive experimental investigation of lunge, applying basic geometrical methods taking near normal lower limb length dimensions and rationale approaches into consideration. Lungeometry can give a foundation to learn other forms of lunges like forward lunge, weighted lunges, lateral lunges. This model of learning biomechanics of movements using fundamental geometry techniques is expected to strongly connect with any futuristic Physiotherapy curricular structure.

KEYWORDS: Lungeometry, Vertical Lunge, Leg-split stance.

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INTRODUCTION

Lower limb movements of humans are very specialized enough to produce tremendous muscular forces in closed kinetic chain (CKC) to derive efficient ground reaction forces notably utilizing leg-split stance to support and move the mass of HAT (Head, Arm & Trunk) interacting with or without any external loads during a wide range of maneuvers compatible to basic activities of daily living, sports, occupational labors and survival competency skills. The overall fitness, especially the lower limb muscular strength levels should be prevented from premature deterioration as a consequence of prolonged sedentary life style accompanied by unfavorable changes in the body mass (excess fat percentage, inadequate muscle mass), culminating in (1) restricted locomotor functions (2) lowered health and fitness competence (3) painful life span harboring incurable health disorders. Therefore, basic and advanced customized exercises used in fitness training and rehabilitation must emphasize on improving the efficiency of closed-kinetic chain lower limb movements like squats, lunges, forward bending, stair climb, getting up from the floor to standing etc, on the basis of health-fitness screening of the individuals. Paul Chek described seven movement patterns; squat, lunge, upper-body pull, upper-body push, bending, twisting and gait [1]. It has become common nowadays to see a large number of people at even very early stages of life demonstrating very poor levels of movement capabilities when tested on the basis of these seven movement patterns as they particularly struggle to squat, lunge, bend, walk and run. Every individual must regularly engage in structured physical activity and preserve all these biomechanically efficient movement patterns as long as they live. Preservation of physical function is a growing concern and decreases in physical capabilities are associated with loss of functional independence; however, these decreases are often attributable to inactivity and not to underlying pathologies [2]. Activities incorporating full range of CKC motions are almost completely fading in the modern life style of quite a lot of people and it is not at all a surprise for exercise professionals if these people succumb to various musculoskeletal disorders and deformities of lower limbs. Lunge is very indispensable CKC movement that basically enables us to get up from the floor from a lying or sitting position to standing position using a leg-split stance biomechanics. Inability to lunge correctly can be equated to a massive strength deficit in lower limbs. In fact, in the domains of musculoskeletal rehabilitation and goal-specific exercise regimens, lunge test can be the best indicator of essential lower limb muscular strength particularly the Quadriceps of the rear extremity. Rectus femoris in the rear leg was found to be more strained during the lunge but still the muscle forces, joint contact forces and joint moments are virtually unknown for nearly all strength training exercises and their various executions [3]. It is well known, that strength training prevents muscle atrophy (Stone, Stone, & Sands, 2007), enhances strength and improves the general health, the body mineral density, the lean body mass, the endurance performance, the insulin sensitivity and other basal metabolism (Wilmore, Costill, & Kenney, 2008) [4,5].

Lunge and its variations are one of the most preferred lower body strengthening exercises. The lunge activated most of the lower limb muscles greater than the squat and it is an ideal activity to train athletes [6]. Strength training of specific muscle groups is also done tactically to prevent abnormal configuration of musculoskeletal system and injuries. Training hip muscles increases lower extremity alignment, improves landing technique, and decreases risk of ACL injury by reducing valgus force to the knee [7]. Gender specific differences in the kinetics may create a problem in the strength training and rehabilitation. Greater Q angle in females was the main gender differences to occur in the kinetics and kinematics of the fencing lunge occurred for the front leg, with no differences occurring for the back leg [8]. Apart from in-depth theoretical understanding of every movement biomechanics, the movement assessment and exercise demonstration skills of the exercise professionals are always a paramount requisite because even a slight fluctuation in the exercise form can expose an individual to injurious forces. A 2° increase in extension from a neutral spine position increased compressive stress within the posterior annulus by an average of 16% compared with maintaining a neutral spine position during lunges [9]. For Physiotherapists to get involved in devising appropriate exercise-based rehabilitation program and advanced researches, the musculoskeletal biomechanics of every joint and its movements must be thoroughly learned in order to relate various relevant scientific literatures and predict the outcomes of strength deficit and movement disorders. To learn the biomechanics of every movement as deep as possible, at least very basic components of mathematics and geometry must be utilized. To kindle the interests of burgeoning Physiotherapists for detailed learning of biomechanics, this article discusses about understanding the lunge using geometric methods with near normal lower limb length dimensions and rationale approaches.

Lungeometry:

Lungeometry is a novel term and technique that deals with investigation of lunge using geometrical methods. The primary requirements for this analysis are geometry instruments and inch tape but additionally tools like goniometer can be included. There are various types of lunges, but for convenience of this basic geometric study, only lunge with a vertical displacement of upright trunk and stable HAT from the ground level has been taken into consideration (only body weight resistance) and also it can be termed as full depth vertical lunge (Photograph-1 & 2).

Photograph-1: This is the starting position of Lungeometry for full depth vertical lunge. The knee of the lead extremity coincides with the metatarsophalangeal joint (MTPJ) region of the lead foot. The knee of the rear extremity is in contact with the ground and the rear foot is perpendicular to the ground with its MTPJ fully extended. The thigh of the rear leg is kept in line with the trunk to eliminate the stretch effects on Iliopsoas muscles. The individual has to overcome the resistance of the upper body (Head, Arm & Trunk - HAT) and vertically uplift the stable HAT, exhibiting the strength and neuromuscular control of lower limbs.

Photograph-2: (a) Finishing position of vertical lunge (b) Finishing position of forward propulsion lunge (c) Finishing position of backward propulsion lunge. For convenience, only vertical lunge has been selected in this analysis. All these mechanisms are examples of CKC motions utilizing leg-split stance.

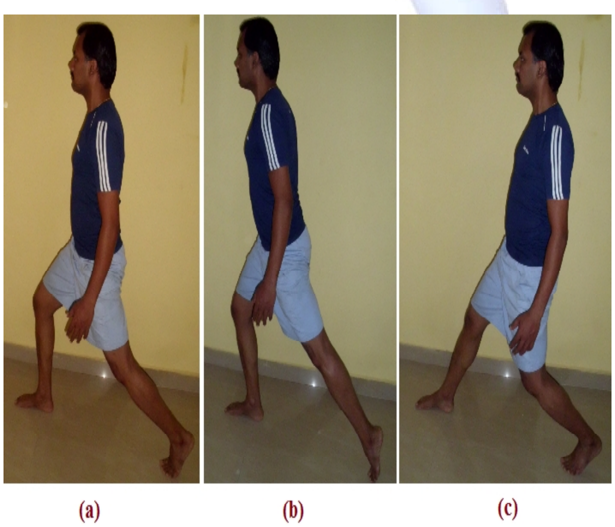
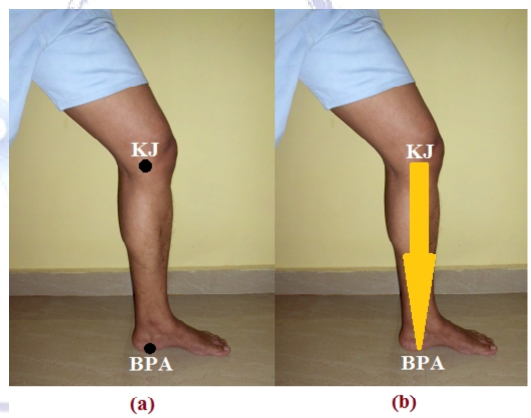


Table-1: Showing the anthropometric dimensions used in this sagittal view analysis.

Height	172 cm
Weight	70 Kg
Thigh length	45 cm (Hip joint to Knee joint)
Leg length	48 cm - Knee joint to the ground that includes the height contribution from talus and calcaneus bones as well which coincides with beginning point of arch of foot (BPA) - Photograph-3
Feet length	25 cm - Divided into three regions; Posterior heel to beginning of arch of foot = 5 cm, Beginning point of arch of foot to Metatarsophalangeal joints (MTPJ) = 15 cm, MTP joints to tip of forefoot preferably tip of great toe = 5 cm.

Photograph-3: The length of the leg is the sum of lengths contributed by tibio-fibular unit, talus and calcaneus. This can be measured from knee joint (KJ) to the ground coinciding with the beginning point of arch (BPA) of foot. This relationship shown in 3a and 3b can also be figured out by examining radiological images and skeleton illustrations in anatomy textbooks.



Lungeometry is divided into two phases (Phase 1 & Phase 2). To ease the geometric drawings, every 5 cm of all these segmental lengths (Table 1) can be considered as 1 cm.

PHASE 1 (Blue colored lines in the Figure - 1 & 2): To understand the alignment of lead and rear extremities when the knee of the rear extremity is in contact with the ground)

Step 1: Draw a 25 cm long dashed horizontal line (HL1) that represents the ground.

Step 2: Find the midpoint of this HL1 and draw a 20 cm long dashed vertical line (VL) upwardly. This midpoint can be named as KJ (Knee joint) of the rear extremity.

Step 3: From KJ, draw a 9 cm vertical line on the dashed VL to represent the thigh part of the rear extremity and its end can be named as HJ (Hip joint) and this point will indicate the level of both left and right hip joints when viewed from sagittal plane. Here we understand that the pelvis should remain horizontal in the coronal plane as normally demanded by a proper lunge.

Step 4: From HJ, draw a 9 cm horizontal line to represent the thigh part of the lead extremity and its end can be named as KJ (Knee joint) of the lead extremity.

Step 5: Plot a point on the HL1 exactly straight below KJ of the lead extremity and this point will represent Metatarsophalangeal joint (MTPJ) of the lead extremity.

Step 6: From MTPJ of the lead extremity, draw a 1 cm line forwardly on the HL1 to represent the great toe length to get the toe region (TR) and draw a 4 cm line backwardly on the HL_1 to represent the length of the rest of the foot till the posterior heel region (HR). On the same line from MTPJ to heel region, plot a point 3 cm away from MTPJ to represent the beginning point of arch (BPA) of lead foot.

Step 7: Join KJ and BPA to get the leg length (knee level to the ground that includes the height contribution from talus and calcaneus bones) and on the basis of drawing, this leg length will be 9.6 cm.

Step 8: With protractor, measure the angles at hip, knee and ankle of the lead extremity. (Hip joint angle in relation to the trunk = 90° flexion, Knee joint angle = 72° flexion, Ankle joint angle = 72° at dorsiflexion.

Step 9: From a point 3 cm above the KJ of the rear extremity, draw a 12.5 cm dashed horizontal line (HL_2) towards the rear extremity side.

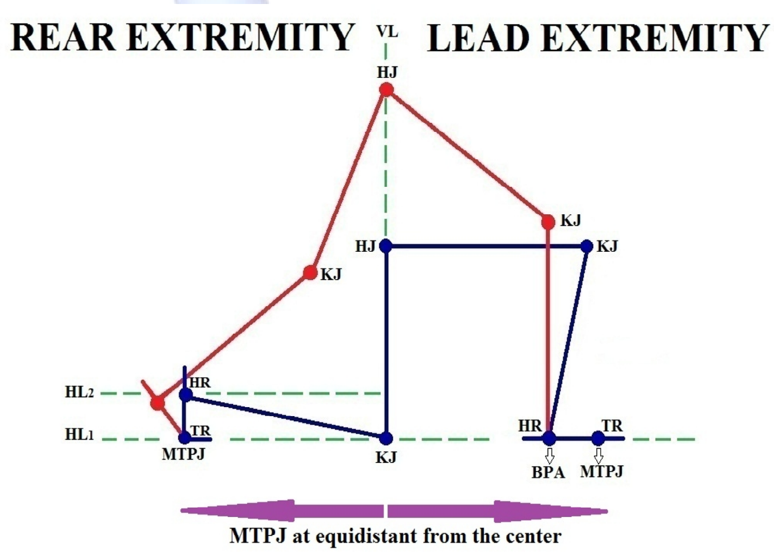
Step 10: Measure 9.6 cm with the compass, fix its needle at point KJ of the rear extremity and draw an arc to intersect the dashed HL_2 (this arc is not shown in the Figure 1 & 2). This point of intersection will represent the BPA of the rear foot. Connect point KJ of the rear extremity and BPA of the rear foot and this line will represent the leg length of the rear extremity.

Step 11: From BPA of the rear foot, draw a 3 cm vertical line downwardly to meet the HL_1 at MTPJ (to represent the portion from BPA to MTPJ of rear foot). Also draw a 1 cm horizontal line from MTPJ of the rear foot forwardly on HL_1 to represent the toe region (TR) of rear foot and draw a 1 cm vertical line from BPA to represent the heel region (HR) of rear foot.

Step 12: With protractor, measure the angles at hip, knee, ankle and MTP joint of the rear extremity. (Hip joint angle in relation to the trunk = 0° (Neutral), Knee joint angle = 72° flexion, Ankle joint angle = 72° at dorsiflexion, MTP joint angle = 90° extension)

This is the arrangement of lower extremities at rest during lunge for the given anthropometric dimensions with the knee of the rear extremity in contact with ground. The geometric procedure should enter into the next phase to understand the interaction of lower extremities as the HAT is lifted vertically upward till the leg of the lead extremity attains a vertical position (from dorsiflexion state to plantarflexion of ankle).

Fig. 1: The starting and finishing position of vertical lunge are shown in blue and red colored lines, respectively, to understand phase-1 Lungeometry. MTPJ of lead extremity and MTPJ of rear extremity have been shown to be at equidistant from the center assuming this as an equilibrium state for proper basic lunge. MTPJ - Metatarsophalangeal joint, HJ - Hip joint of right and left extremities, KJ - Knee joint, BPA - Beginning point of arch of foot, TR - Toe region, HR - Heel region, HL_1- Dashed horizontal line drawn at first, HL_2- Dashed horizontal line drawn to configure the rear leg and foot, VL - Dashed vertical line.



PHASE 2 (All red colored lines in the Figure 1 & 2): To understand the alignment of lead and rear extremities after the HAT is vertically uplifted till the leg of the lead extremity attains a vertical position and maintains a 90° relationship with the lead foot)

Step 13: Draw a 9.6 cm vertical line from BPA of the lead extremity and its end will be KJ of the lead extremity displaced upwardly and backwardly.

Step 14: Measure 9 cm with the compass, fix its needle at the displaced point KJ of the lead extremity and draw an arc (Arc 1) to intersect the dashed VL. This point of intersection will represent the vertically displaced HJ of the lead and the rear extremity considering the pelvic alignment as horizontal in the coronal plane. Draw a line from this HJ to KJ to get the thigh part of the lead extremity.

Step 15: With protractor, measure the angles at hip, knee and ankle of the lead extremity. (Hip joint angle in relation to the trunk = 42° flexion, Knee joint angle = 138° flexion, Ankle joint angle = 90° and the posterior tilt of the leg or magnitude of ankle plantarflexion from dorsiflexion = 20° approximately).

Step 16: It looks like there is necessity for the rear foot (BPA to MTPJ portion) to tilt backwardly using its MTP joint axis. The magnitude of this tilt can be around 50% more than the posterior tilt of the leg of the lead extremity. So, draw a 3 cm line at 30° angle (20° + 10°) from the MTPJ deviated backwardly and its end will be the displaced BPA of the rear foot and along with that, its heel portion (HR) also gets automatically aligned in the same angle.

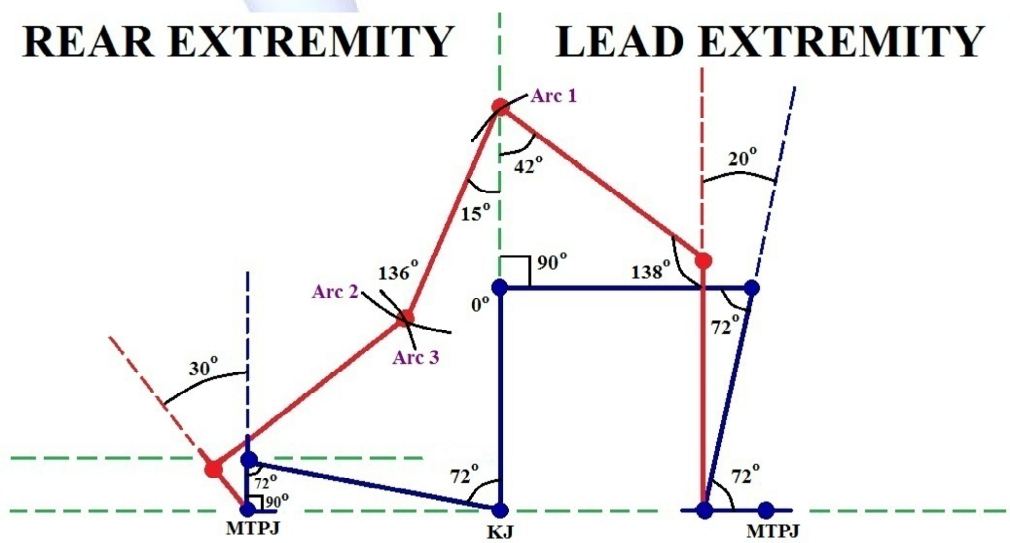
Step 17: Measure 9 cm with the compass, fix its needle on the vertically displaced HJ and draw an arc (Arc 2) towards the ground. Measure 9.6 cm with the compass and from the point of backwardly displaced BPA of the rear foot; draw another arc (Arc 3) to intersect the Arc 2 to get KJ.

Step 18: With protractor, measure the angles at hip, knee and ankle of the rear extremity. (Hip joint angle in relation to the trunk = 15° extension, Knee joint angle = 136° flexion, Ankle joint angle = 90° and the MTP joint angle = 120° extension (but 30° moves towards flexion).

Step 19: Measure the distance between HJ and the displaced HJ which will equal 7.3 cm indicating the total vertical displacement of the HAT.

Step 20: Observe the finished drawing closely to (i) relate the findings with goniometric studies (Photograph-4) on human subjects (ii) understand the inter-extremity and intra-extremity joint adjustments during ascent and descent phases of vertical lunge (iii) calculate the work done (iv) understand various scientific literatures pertaining lunge kinetics and kinematics.

Fig. 2: The arcs, point of intersections and joint kinematic angles of the lead and the rear extremity at the starting and finishing position of vertical lunge are shown to understand phase-2 Lungeometry.



Photograph-4: 4a & 4b shows samples of goniometer utility in the kinematic analysis of vertical lunge while doing Lungeometry.

(a) (b)

The body weight of the individual used in this analysis is 70 Kg. It is possible that the HAT mass can be, based on the studies of body segment parameters of de Leva and Plagenhoef et al, up to 59.26 % and 73.12%, respectively [10,11]. If we take the report of de Leva for consideration, then the HAT mass of this 70 Kg individual will be 41 Kg, so 410 Newton (F) approximately. Work is defined as force (F) applied against a resistance, multiplied by the displacement (d) of the resistance of the direction of the force (W=Fd) [12]. As a result of this sample Lungeometry, the vertical displacement of the hip (on which the HAT is placed) was found to be 7.3 cm, so in real it will be 36.5 cm because in the geometric drawing analysis every 5 cm of the segmental length was considered to be 1 cm. This vertical displacement (d) should be converted into meters for calculation of work done. Therefore, the work done for uplifting the HAT mass used in this scenario equals 150 joules approximately (410 N x 0.365m).

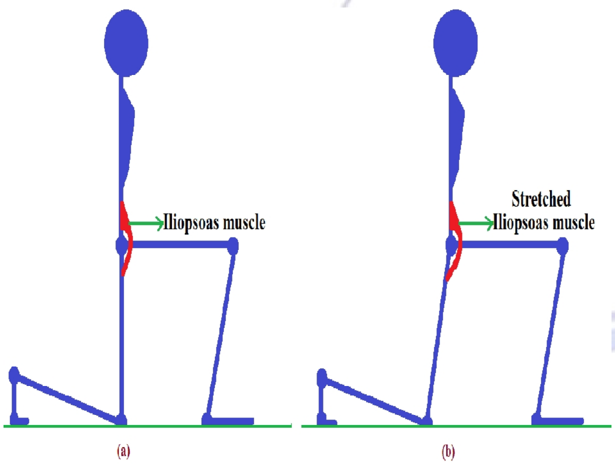
The muscular role in lead and rear extremity during lunges can also be partly understood observing at the Lungeometric illustrations. In vertical lunge, as the rear foot is aligned vertical with MTPJ in complete extension, the rear extremity must apply force on the ground. To accomplish this rear foot force application, the entire foot must remain highly stable without medio-lateral and antero-posterior movement at the ankle and the foot. A variation of lunge is forward lunge and during the performance of the forward lunge, ankle mobility on both the lead and trail legs is critical to ensure a balanced biomechanically correct lunge pattern [13]. As shown in the photograph-5, the foot should be aligned stable without medio-lateral motions because the rear leg can be the key force supplier for the vertical lunge and also various other multi-directional lunges commonly used in sports, exercise training and activities of daily living. Upon analysis of the lunge, it was found that power production of the lower limbs occurred almost exclusively from the trail leg [14].

Photograph-5: 5a shows proper foot alignment for effective propulsion during lunge. 5b & 5c shows medial and lateral deviations of heel, respectively, that can affect the propulsive biomechanics of lunge.

(a) (b) (c)

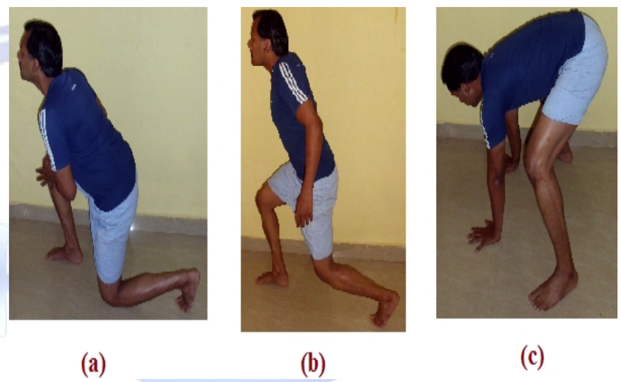
At the same time, the stability of the lead extremity is also vital for a proper lunge. The cause of mediolateral movement of the lead knee during a forward lunge is hypothesized to be poor strength or activation of the rectus femoris, hamstrings, and hip abductor and adductor muscles [15]. The rear extremity, for the most part of the vertical lunge, should solely rely on CKC knee extension produced by Quadriceps to impart the vertical upward thrust force to the femur (via the tibio-fibular unit of leg) to lift the HAT but the extent, angle and duration of this upward thrust force on femur can be very soon controlled by accompanying hip extension and ankle plantarflexion which naturally alter the alignment of the foot, leg and thigh of rear extremity (Intra-extremity adjustments) to determine the alignment of the pelvis. Flexibility of all lower limbs muscles is vital for all CKC activities. For example, tightness of Iliopsoas muscle can interfere with proper trunk alignment, hip extension kinematics and force contributing mechanisms of rear extremity, potential enough to ruin proper lunge form completely (Figure-3).

Fig. 3: 3a schematically shows the Iliopsoas muscle crossing the hip joint. This hip flexor can severely affect the lunge form if it is inflexible. Physiotherapists may have to pay closer attention to this muscle's flexibility and if found tight, the lunge posture with increase in the distance between the knee of rear extremity and heel of the lead extremity (with rear hip extension) can be chosen to stretch the Iliopsoas as commonly seen in flexibility programs (3b).



In vertical lunge, on the other hand, the lead extremity undergoes a different mechanism to apply upward thrust to the femur to lift the HAT with the lead foot completely contacting the ground but the tibio-fibular unit approaches vertical position caused by CKC plantarflexion of ankle. While the CKC ankle plantar flexion of the lead extremity appears in the biomechanical play of vertical lunge, there will be tendency for the pelvis to be rotated posteriorly in the transverse plane in the same side; hence the ongoing intra-extremity adjustment of the rear extremity can counteract and ensure the transverse plane pelvic stability (Inter-extremity adjustments). Gluteus maximus and Vasti muscles can apply force couple mechanics (FCM) on femur to lift the HAT mass during closed kinetic chain activities of lower limbs [16]. The critical role of FCM on femur of lead extremity in different lunges should be explored further but may be an integral part of lunges with forward trunk propulsions (Photograph-2b). All safe and productive CKC motions, including vertical lunge, occurs as a result of skilled application of forces on the ground, using the requisite strength of the lower limb muscles to derive appropriate ground reaction forces. Various individuals exhibit immense difficulty in applying appropriate ground reaction forces while getting up from the floor (Photograph-6). Runners reach faster top speeds not by repositioning their limbs more rapidly in the air, but by applying greater support forces to the ground.[17]

Photograph-6: 6a shows the very common strategy used to get up from the floor in which individuals apply force on their lead extremity through hands to compensate for the inability to lunge properly and independently. 6b shows another finding in which individuals lacking lower limb strength exhibit a jerky shoulder shrugging in the ascent phase of lunge. 6c shows the strategy of individuals with very weak lower limb strength and neuromuscular control as they cannot lunge and get up at all, almost resembling Gower's sign in Muscular dystrophy. When asked to get up from the supine lying to standing position as quick as possible with proper lunge incorporated, individuals with average and above-average fitness levels take ≤ 2 seconds only.



CONCLUSION

At least one repetition of vertical lunge (on both sides) with upright trunk from the ground can be used as an integral physical efficiency assessment done by Physiotherapists. Inability to perform at least one full depth vertical lunge (on any one side or both sides) can be considered as a substantial deficit in muscular strength and neuromuscular control of lower extremities which may be most likely linked with difficulty in performing other forms of lunges and general locomotor functions also. Early identification of the biomechanical factors responsible for a defective full depth lunge and designing of strategic exercise protocols for quick restoration of full depth lunge, can prevent rapid tapering of lower limb strength and functional independency caused by predictable and unpredictable medical ailments. Efficient Ground reaction forces Notably Utilizing Leg-split stance (Acronym of LUNGE in the reverse order) can be learned, applied and researched in detail by Physiotherapists through easy and inexpensive investigations like Lungeometry.

Conflicts of interest: None

REFERENCES

[1]. Chek P. Movement That Matters. San Diego, CA: C.H.E.K Institute, 2000. pp. 54.

[2]. Flanagan SP, Wang MY, Greendale GA, Azen SP, Salem GJ, Biomechanical attributes of lunging activities for older adults, J Strength Cond Res. 2004 Aug;18(3):599-605.

[3]. Schellenberg F, Ramseier M, Lorenzetti S., Muscle Forces of Quadriceps and Hamstrings during Lunges, Jahrestagung der SGS 2013 in Basel.

[4]. Stone, M. H., Stone, M., Sands, W. Principles and Practice of Resistance Training: Human Kinetics, 2007.

[5]. Wilmore, J. H., Costill, D. L., Kenney, W. L., Physiology of Sport and Exercise, 4th edition: Human Kinetics, 2008.

[6]. Priscilla Dwelly, Gretchen Oliver, Heather Adams-Blair, David Keeley, Hiedi Hoffman, Improved muscle activation in performing a body weight lunge compared to the traditional back squat - Retrieved from https://ojs.ub.uni-konstanz.de/cpa/article/view/3341/3141, 27 International Conference on Biomechanics in Sports (2009), pdf.

[7]. Myer, G.D., Chu, D.A., Brent, J.L., Hewett, T.E., Trunk and hip control neuromuscular training for prevention of knee injury. Clinics in Sports Medicine 2008;27:425-448.

[8]. 8. Jonathan Sinclair, Lindsay Bottoms, Gender differences in the kinetics and lower extremity kinematics of the fencing lunge - International Journal of Performance Analysis in Sport, 2013;13:440-451.

[9]. Hollman JH, Kolbeck KE, Hichcock JL, Koverman JW, Krause DA, Correlations between hip strength and static foot and knee posture. J Sport Rehabil, 2006;15:12–23.

[10]. de Leva P, Adjustments to Zatsiorsky-Seluyanov's Segment Inertia Parameters, Journal of Biomechanics, 1996;29(9):1223-1230.

[11]. Plagenhoef, S., Evans, F.G., Abdelnour, T., Anatomical data for analyzing human motion. Research Quarterly for Exercise and Sport, 1983;54:169-178.

[12]. Susan J Hall, Basic Biomechanics, Chapter-12, Linear kinetics of Human movement, Brown & Bench mark, 1991.

[13]. Bennell K, Talbot R, Wajswelner H,Techovanich W, Kelly D, Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. Aust J Physiother, 1998;44:175–180.

[14]. Nathan Morris, Mark Farnsworth, D.G.E. Robertson, Kinetic analyses of two fencing attacks – lunge and fleche, Portuguese Journal of Sport Sciences, 2011;11(Suppl. 2).

[15]. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM, Relationship between hip and knee strength and knee valgus during a single leg squat, J Appl Biomech, 2006;22:41–50.

[16]. R.Vinodh Rajkumar, Force couple mechanics on femur during closed kinetic chain activities of lower limbs. Int J Physiother Res 2014;2(6):766-771.

[17]. P G Weyand, D B Sternlight , M J Bellizzi ,S Wright, Faster top running speeds are achieved with greater ground forces not more rapid leg movements, Journal of Applied Physiology 12/2000; 89(5):1991-9.

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