International Journal of Health Sciences and Research
www.ijhsr.org ISSN: 2249-9571

Original Research Article

The Relationship between Vertical Jump Performance and Peak Torque of Lower Limb Muscles among Basketball Players

Kriti Singh[1], Soni Satish[2], Nanda Kumar. S[3]

[1]Assistant Professor, D. Y. Patil School of Physiotherapy, Navi Mumbai India
[2]Associate Professor, Department of Physiotherapy, Ramaiah Medical College and Hospitals, Bangalore, India
[3]Assistant Professor, Department of Physiotherapy, Ramaiah Medical College and Hospitals, Bangalore, India

Corresponding Author: Nanda Kumar. S

ABSTRACT

Background: Basketball game demands good muscle strength and an anaerobic power of lower extremities for best performance during the game. The vertical jump is one of the most explosive physical movements performed in basketball game and shooting is the basic way to get scores in basketball. For this reason, jump shot is the most frequently training method used in basketball academics. Literatures on muscle strength training to improve vertical jump performance among athletes are well established. However there is no detailed information of association of mechanical contribution of hip, knee or ankle with vertical jump with respect to the jump training regime, whether training program should include eccentric or concentric strength training techniques.
Aim of the study: To find the correlation between vertical jump performance and peak torque of lower limb muscles among basketball players.
Method: Through convenience sampling 39 collegiate basketball players were recruited after screening for inclusion and exclusion criteria. Isokinetic concentric peak torque of hip extensors (180^0/sec), knee extensors (120^0/sec) and plantar flexors (120^0/sec) was assessed for dominant lower limb with 5 repetitions. After recording the peak torque, the subjects will be made to rest for 15 minutes and vertical jump test with 3 trails were recorded.
Data Analysis: Descriptive statistic of concentric peak torque of hip, knee and ankle muscles and vertical jump performance were analyzed in the term of mean and standard deviation. Spearson's correlation coefficient between peak torque of hip, knee and ankle muscles and vertical jump scores were correlated and 2 –tailed significance t test was done for significance.
Results: significant correlation of concentric peak torque of knee extensors at angular velocity of 120^0 per sec with vertical jump was noted. Further linear regression coefficient correlation was found between concentric peak torques of knee extensors with vertical jump.
Conclusion: The result of this study indicates the significant correlation of peak torque of knee extensors at angular velocity of 120^0 per sec with vertical jump performance among basketball players. The knee extensors seem to be the greater contributor for vertical jump performance

Key words: Vertical jump, isokinetic strength, knee extensors torque

INTRODUCTION

Basketball is one of the World's favourite and popular sports which are viewed widely all over the world. [1] Basketball is a game of speed, quickness and vertical jumps which involves the rebound, dribble, blocks and jump shots. [2] The main movements in basketball are sprinting, pivoting and jumping which involves the muscles of upper limbs, trunk and lower limbs. Basketball is a dynamic sport which activates muscles throughout the body to a complex coordinate multi joints movement with precision. Basketball players should possess a good muscular endurance, strength and stamina to produce an explosive power and speed during the game performance. Basketball training academies all over the world concentrate on training regime of muscle strength which involves the movements like sprinting, jumping and shooting. [3] The players improve their game performance by repeated practicing of jumping and shooting during the practice sessions.

Basketball sports demands good muscle strength and an anaerobic power of lower extremities for best performance during the game. [4] Shooting is the basic way to get scores in basketball and for this reason; jump shot is the most frequently used training method in basketball academics. [5,7,1] The effectiveness of jump shot totally depends on the accuracy and torque production from the lower limb muscles. The stronger the strength of lower limb muscles, the more torque production the body can generate during the vertical jump. [6] The force production from the lower limb muscles are applied in the same direction of the vertical jump and a proper sequence of recruitment pattern of lower limbs muscles is reported. [7] The sequence of muscle activation occurs during vertical jump is through a proximal to distal pattern. The muscles which are closest to the center of mass that is Gluteus Maximus and hamstring are activated first. The energy is then transferred continuous with quadriceps and Gastrocnemius and Soleus. The important biomechanical principle of better vertical jump is the summation of forces produced from all lower limb muscle groups. [8, 9]

Biomechanical research have reported that two joint muscles of hip extensors (Hamstring), Knee extensor (Quadriceps- Rectus Femoris) and Gastrocnemius (plantar flexors) are most important muscle recruited during the vertical jumping. [9] Addition to this report it is revealed that the functional capacity of two joint muscles depends on the stronger contraction proximal one joint muscle (gluteus maximus). The stronger the proximal one joint muscle contract, the maximal mechanical energy is redistributed to the distal two joint muscles to generate explosive leg extension during vertical jump. [10,11,9]

Vertical jump can be defined as a complex series of ballistic multi joint movement where the muscles around the thighs, knees and ankle joints work collectively to create pattern of movement of push off, flight and lastly landing. [12] A typical vertical jump consists of two phases of movements. A preparatory flexion phase is produced by an eccentric contraction of hip, knee and ankle muscles followed by propulsive extension phase produced by concentric contraction of hip, knee and ankle extensor muscles. [13]

The mode of muscle activation during vertical jump is concentric contraction of extensors of lower limb muscles preceded by an eccentric contraction of flexors of lower limb. There are two types of vertical jumps are performed by basketball players. Squat jump which is performed without arm swing and no countermovement and the vertical counter movement jump are performed with arm swing with rapid flexion of hip, knee and ankle joints. [14,15] The studies have indicated the primary muscles recruited during squat jump are knee extensors but during countermovement jump along with knee extensors, plantar flexors provide the breaking force before taking off. [16,17]

The ability to perform a vertical jump is a reliable indicator of lower limb power which has been validated across a wide range of sports population. [18,19]
Lower limb muscles power and vertical jump performance are considered as critical elements for successful athletic performance including basketball players. [20,14] Although the summation of forces from all muscles of lower extremity is essential in producing

effective vertical jump. There are few literatures which have shown discrepancies on evidence in reporting the importance muscle for vertical jump performance. Hubley and Wells reported that 49% of the total positive work produced during the vertical jump was attributed to knee muscles, with 28% and 23% done by the hip and ankle muscles, respectively. [21] In contrast, Fukashiro and Komi reported that the greatest contributor to vertical jump performance was the hip muscles (51%) followed by the knee (33%) and ankle (16%). [22] Vanezis and co workers reported a conflicting data that there is no significant different of kinetic and kinematic variables of good and poor performers of vertical jump. [23] Asnoted by Vanezis and Lees, the good jumpers exhibited significantly higher ankle work done than poor jumpers and the hip or knee work done was not significantly different between the two groups. In addition, there is also discrepancies of evidences on the type of muscle contraction either concentric or eccentric is important for vertical jump. Norkin and coworkers reported that eccentric contraction of lower limb muscles produces stronger force than their concentric counterpart muscles during vertical jump. [24] Hortobagy & Katch reported that eccentric contraction has negative relationship with movement velocity compared with concentric contraction of lower limb muscles. [25] In contrast to these literatures, Oddsson and coworkers reported that measures of both concentric and eccentric strength were very similar related to vertical jump performance. [26]

The basis of the basketball game demands two main functions that is the extensor mechanism: the accelerating function with a concentric contraction during vertical jump and the decelerating function with an eccentric contraction observed in the phase of landing. [27] Due to such demand on the extensor mechanism, if there is any imbalances between the extensor and flexor muscles may be cause an overloading to the muscle tendinous structures around the knees joint and ankle leading to injuries. [28]

There is no detailed information to explain which major muscles around lower limb joints contribute to explosive performance during vertical jump. There is also no clarity of association of mechanical contribution of hip, knee or ankle with vertical jump with respect to the jump training regime, whether training program should include eccentric or concentric strength training techniques. Plyometric training has reported by many researchers shown improvement in vertical jump ability and leg muscle power among basketball, volleyball and other sports. [29] Several researches have demonstrated the positive effect of resistive concentric training methods on vertical jump performance. [30-32] In light of the potential importance, this study is carried out to find the Isokinetic concentric torque of hip extensors, knee extensors and plantar flexors and correlate with vertical jump scores and to identify the most important muscle in vertical jump among basketball players. Clinical implication of this study would provide information about which muscle should be trained for enhancement of jump height during vertical jump among basketball players.

MATERIALS ANS METHODS

Objectives of the study

1. To correlate the Isokinetic torque of hip extensor, knee extensors and plantar flexors with vertical jump performance among basketball players
2. To identify the most important muscle for vertical jump.

TYPE OF THE STUDY: Correlation study

METHODS OF SAMPLING:

Convenience sampling

SAMPLE SIZE: 39

Sample size was calculated based on study - Black burn observed that the relationship between open kinetic chain strength score and vertical jump performance was r = 0.722. In the present study expecting similar result with 80% power, 95% confidence interval and considering the relationship of r = 0.88 in the population requires minimum of 39 subjects.

Sources of collection of data: M.S Ramaiah Medical College basketball players

INCLUSION CRITERIA:

1. Age group: 18-25 years
2. Male basketball players who represent M S Ramaiah College Team.
3. Middle BMI scores

EXCLUSION CRITERIA:

1. Any recent injuries of hip , knee or ankle
2. Any pathology preventing isokinetic testing (eg. Lumbar nerve root compression, myopathy).
3. Person undergoing any form plyometric training
4. Knee surgery or intra-articular corticosteroid injection within the past 6 months
5. Knee instability or sensation of knee "giving out"
6. Unable to perform vertical jump
7. Presence of other disorders affecting the lower limbs (such as plantar fascitis)

MATERIALS REQUIRED

1. Isokinetic dynamometer (Cybex, humac norm)
2. Vertical jump test recording sheet

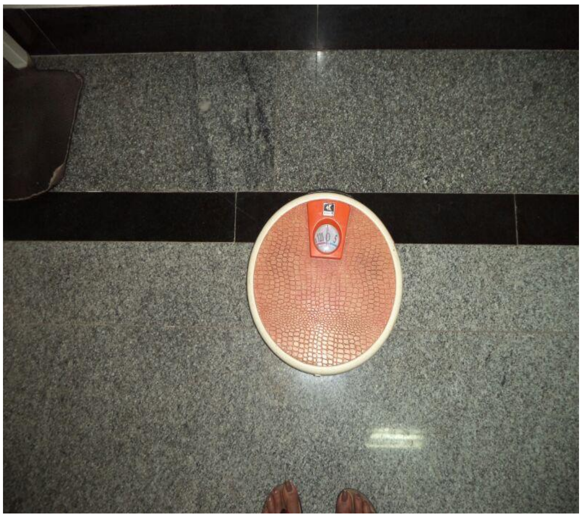

Figure 1. Weighing machine

Figure 2. Isokinetic Machine

Figure 3. Measuring the peak torque of Hip muscles

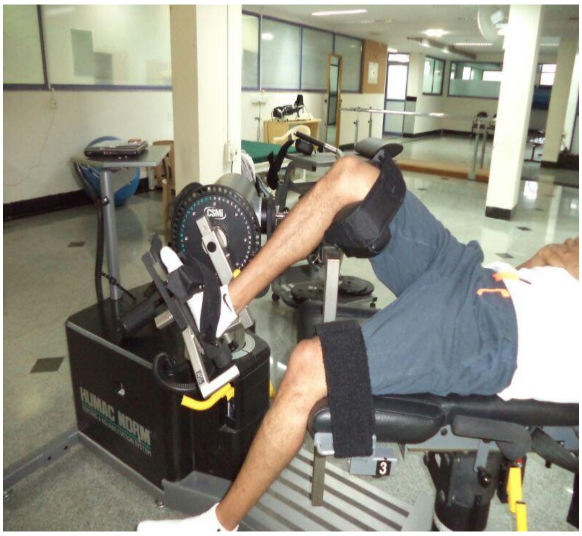

Figure 4. Measuring the Peak torque of Ankle Muscles

Figure 5. Measuring the Peak Torque of Knee uscles

Figure 6. Preparing for Vertical Jump

Figure 7. Vertical Jump

Figure 8. Maximum vertical jump

An ethical clearance was obtained from the ethical committee of M.S. Ramaiah Medical College. Collegiate male basketball players were assessed for their eligibility. If the subjects fulfilled the inclusion and exclusion criteria, an information sheet providing details about the study was provided to them. For subjects who were willing to take part in the study, an informed consent was obtained from them for the same. Prior to the assessment of peak torque, a demographic data was collected. The age, height in cms and weight in kgs were recorded for all subject for calculation of BMI .All subjects were assessed for their baseline peak quadriceps torque (which is normalized to their body weight) using an isokinetic dynamometer (Cybex, humac norm). After familiarizing the subjects with the working of the machine with sub maximal trial repetitions, they were made to rest for 30 minutes to account for factors of pain or fatigue of the muscle. During testing, visual and verbal encouragement was given for achieving the maximum capable peak torque. Following this, Isokinetic concentric torque of hip extensors (180^0/sec) with range of motion of 60^0flexionto 0^0extensionwas calculated. The subjects were tested in supine position. The subjects were strapped into the chair. The concentric peak torque of hip extensor was calculated in gravity elimination with 3 trails and 5 repetitions. The best repetition score was recorded. Five minute of rest was given before assessing knee extensor peak torque.

Isokinetic concentric torque of knee extensors (120^0/sec) with range of motion of 90^0flexionto 0^0extensionwas calculated. The subjects were made to sit in high sitting position. The subjects were strapped into the chair using the lateral femoral condyle as an anatomical reference for the axis of rotation. The concentric peak torque of knee extensor was calculated in gravity elimination with 3 trails and 5 repetitions. The best repetition score was recorded. Five minute of rest was given before assessing ankle plantar flexor peak torque.

Isokinetic concentric torque of ankle plantar flexors (120^0/sec) with range of motion of 0^0neutral position to 50^0 of plantar flexion was calculated. The subjects were made to sit in high sitting position. The subjects were strapped into the chair. The concentric peak torque of ankle plantar flexors was calculated in gravity elimination with 3 trails and 5 repetitions. The best repetition score was recorded. [33,34]

After recording the peak torque of hip extensor, knee extensor and plantar flexors, thirty minute of rest was given before assessing vertical jump.

Procedure of vertical jump: the players were made to stand on side to a wall and reached up with the hand closest to the wall with their feet flat on the ground. The point of the fingertips was marked which is called as standing reach (m1). The player was asked to put colour powder on their fingertips to mark the wall at the height of their jump. The players were then asked to stand away from the wall and instructed to jump vertically as high as possible in attempt to touch the wall at the highest point of the jump (m2). The difference in distance between the standing reach height and the jump height was calculated. The best of three attempts scored of vertical jump was recorded.

STATISTICAL METHOD

The data collected were entered in Microsoft Excel and statistical analysis was performed using the Statistical Package for Social Sciences (SPSS version 16) software. Descriptive statistic of open kinetic peak torque of hip, knee and ankle muscles and vertical jump performance were analyzed in the term of mean and standard deviation. Spearson's correlation coefficient between peak torque of hip, knee and ankle muscles and vertical jump scores were correlated and 2 –tailed significance t test was done for significance.

Linear regression analyses were used to find out factors affecting vertical jump and to identify the importance muscle for better vertical jump performance.
Sensitivity and specificity test was done for vertical jump and peak torque of hip, knee and ankle muscles.

RESULTS

Demographic data of samples (age and BMI) are shown in the table below

TABLE 1: Range, Mean and SD of Age and BMI

	Range	Mean	Std Deviation
Age group	18.00 – 25.00	21.00	1.46
BMI	19.40 – 24.81	22.54	1.43

The above table shows the range, mean and standard deviation of Age group and BMI.

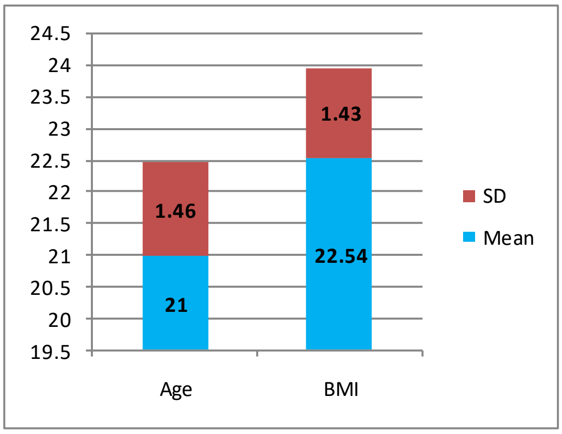

FIGURE 1: Graphic representation of Mean and standard deviation of Age group and BMI scores of subjects

TABLE 2: Range, Mean and SD of physical parameters

Variables	Range	Mean	Std Deviation
Vertical Jump	42.72 – 51.54	47.13	13.61
Knee	80.84 – 98.18	89.51	26.74
Hip	26.06 – 32.20	29.13	9.46
Ankle	23.53 – 27.09	25.31	5.49

The above table shows the range, mean and standard deviation of vertical jump scores and peak torque of Hip, Knee and Ankle muscles of samples (n = 39)

TABLE 3: Correlation between vertical jump with physical parameters (Hip, Knee and Ankle)

Vertical jump	Knee	Hip	Ankle
Correlation coefficient	r = 0.922**	r = 0.446**	r=0 .076 ^{ns}
Sig. (2- Tailed)	p=0 .000	p = 0.004	p= 0.644
** Correlation is significant at the 0.01 level (2-tailed).			

** denotes significance at 5% i.e., p< 0.05
NS denoted not significant at 5% i.e., p> 0.05

The above table shows significant correlation between peak torques (concentric) of hip extensor at angular velocity of 180^0 per second (p = 0.004) and Knee extensor at angular velocity of 120^0 per second (p = 0.000) with vertical jump. There is no significant correlation between peak torque (concentric) plantar flexor at angular velocity of 120^0 per second with vertical jump (p = 0.644).

TABLE 4: Statistical outcome of linear regression of vertical jump on peak torques of Knee and Hip extensor

Vertical Jump	Regression coefficient	t- value	p- value
Constant	4.998	1.489	0.145
Knee	0.461	10.979**	0.000
Hip	0.029	0.248 ^{ns}	0.805

** denotes significance at 5% i.e., p< 0.05
NS denoted not significant at 5% i.e., p> 0.05

The above table shows significant linear correlation of peak torque (concentric) Knee extensor at angular velocity of 120^0 per second with vertical jump (p= o.oo0) and no significant linear correlation of peak torque Hip extensor at angular velocity of 180^0 per second with vertical jump

Note: Since peak torque (concentric) of ankle plantar flexors at angular velocity of 120^0 per second was not showing significant correlation with vertical jump, it was vomited from regression model.

TABLE 5: comparison of range, Mean and SD of physical parameters of subjects with Vertical jump score ≥ 50 cm and < 50 cm

	Vertical jump				t - value	p- value
	≥ 50 (n= 14)		<50 cms (n= 25)			
Variables	Mean	S D	Mean	S D		
Knee	116.21	19.55	74.56	16.61	7.04**	0.000
Hip	37.86	9.38	24.24	4.98	5.94**	0.000
Ankle	26.93	7.66	24.40	3.68	1.39^{ns}	0.262

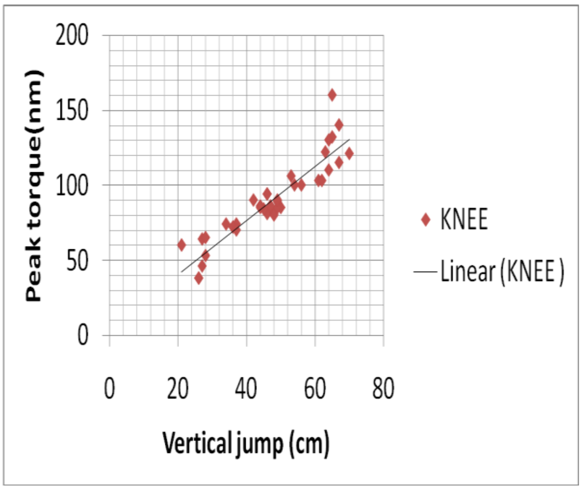

FIGURE 2: Graphical representation of relation between peak torque of knee extensor and vertical jump

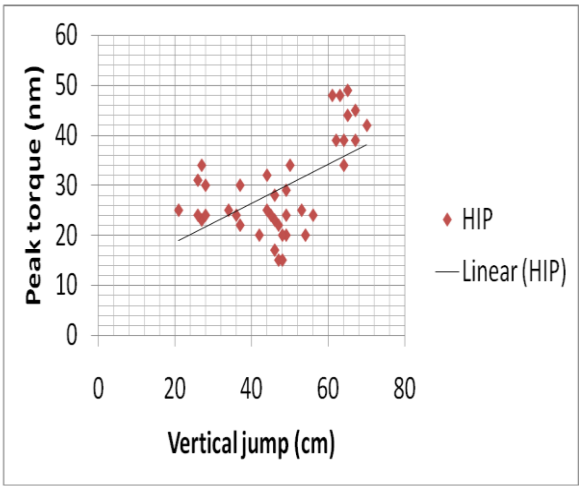

FIGURE 3: Graphical representation of relation between peak torque of hip extensor and vertical jump

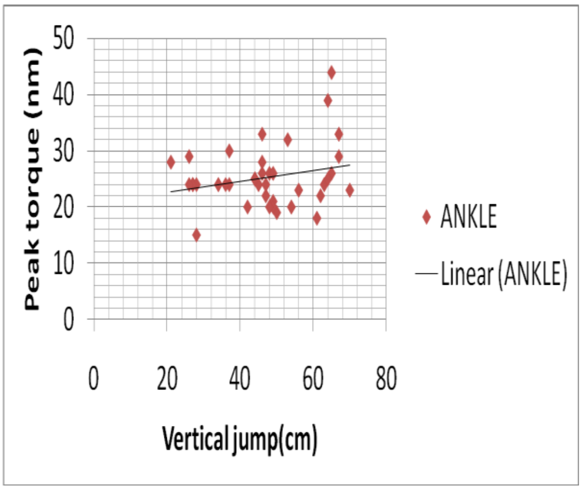

FIGURE 4: Graphical representation of relation between peak torque of Ankle plantar and vertical jump

The above table shows the comparison means values of peak torques (nm) of hip extensor, knee extensor and ankle plantar flexor with vertical jump scores of subjects (n =14) ≥ 50 cm and subjects (n = 25) < 50 cm

TABLE 6: statistical significance of physical parameters of subjects with Vertical jump score ≥ 50m and < 50 cm

	Vertical jump ≥ 50 cms (n= 14)			< 50 cms (n= 25)		
Variables	Range	Mean	S D	Range	Mean	S D
Vertical Jump	50-70 cm	61.50	5.97	21-49 cm	39.08	9.27
Knee	85-160 nm	116.21	19.55	38 – 94 nm	74.56	16.61
Hip	20-49 nm	37.86	9.38	15-34 nm	24.24	4.98
Ankle	18-44 nm	26.93	7.66	15-33nm	24.40	3.68

** denotes significance at 5% i.e., p< 0.05
NS denoted not significant at 5% i.e., p> 0.05

The above table shows significant correlation between of peak torques of knee extensor and hip extensor of both strata of vertical jump scores of ≥ 50m and < 50 cm. There was no significant correlation between peak torques of ankle plantar flexors with both strata of vertical jump scores ≥ 50m and < 50 cm

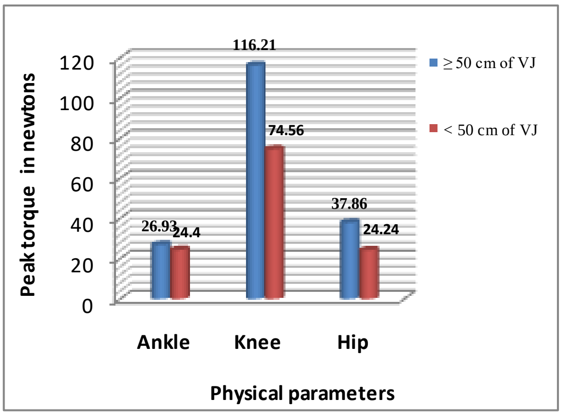

FIGURE 5: Graphical representation of comparison of peak torques of Hip extensor, Knee extensor ad Ankle Plantar flexors with Vertical jump score of subjects with ≥ 50 cm and < 50 cm

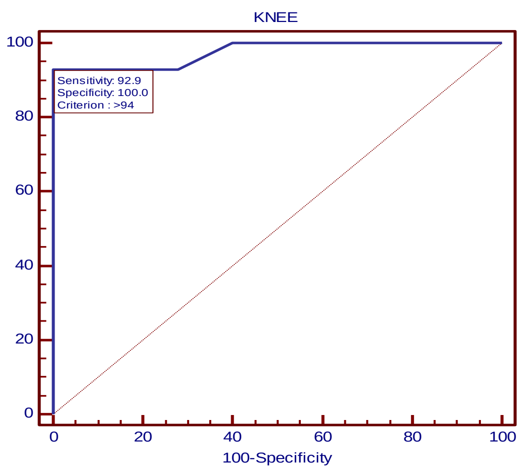

FIGURE 6: Graphical representation of sensitivity and specificity of peak torque knee extensors with vertical jump

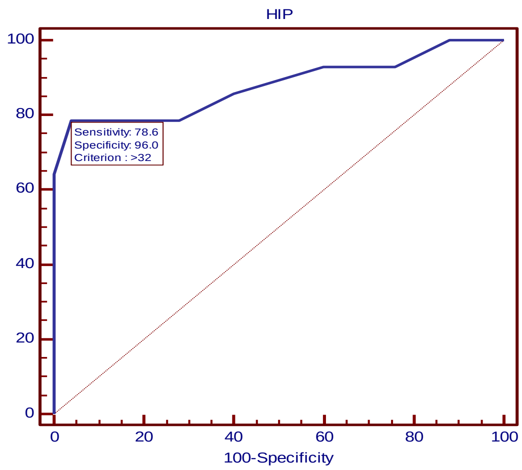

FIGURE 7: Graphical representation of sensitivity and specificity of peak torque hip extensors with vertical jump

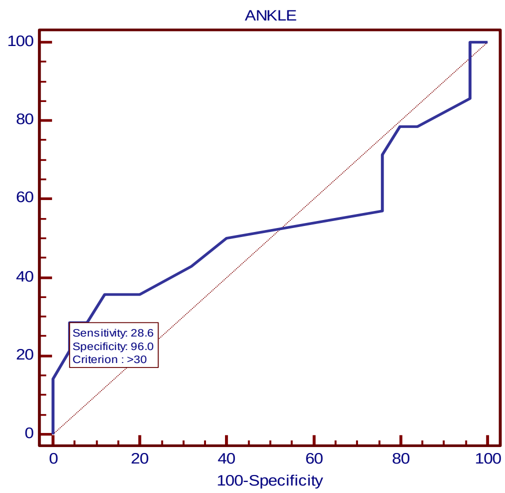

FIGURE 8: Graphical representation of sensitivity and specificity of peak torque ankle plantar flexors with vertical jump

DISCUSSION

The main aim of this study was to correlate the Isokinetic torque of hip extensor, knee extensors and plantar flexors with vertical jump performance among basketball players and to identify the most important muscle for vertical jump. The tested group of collegiate basketball players had similar body mass index and stature. Our result indicates that there is significant correlation between concentric knee extensor peak torques at angular velocity of 120^0 per second with vertical jump. There was no significant correlation between concentric hip extensor peak torque at angular velocity of 180^0 per second and ankle plantar flexor peak torque at angular velocity of 120^0 per second with vertical jump, there by supporting the first part of our research hypothesis. Similar results were presented by Anthony Theoharopoulos using the testing speed on professional basketball players. [35] One plausible reason could be that they were tested on professional basketball players who would have undergone sports specific training for vertical jump and small sample size (n = 12). Whereas the current study was conducted collegiate male basketball players and sample size of n= 39. Our study findings support the results of study reported by Hubley and Wells that the greatest contributor to the vertical jump was knee extensors (49 %), followed by hip extensors (28%) and ankle plantar flexors (23 %). [21]

The result of our study has shown the interesting pattern of contribution of concentric peak torque among lower limb muscles. Knee extensors have shown the greater value of concentric peak torque among all the subjects, followed by concentric hip extensors and concentric ankle plantar flexors. The important biomechanical principle of better vertical jump depends on the vertical velocity take off which is turn is the summation of muscle torques produced from all the joints involved in vertical jump. [26,9,8]

The possible explanation which can be attributed to our study is through the biomechanical basis of muscle action during vertical jump. Kinetic analysis studies have reported the sequence of muscle activation occurs during vertical jump is through a proximal to distal pattern. The hip extensors are the proximal musculature which includes Gluteus Maximus (GM) and Hamstring muscles. GM has shown greater impact on vertical jump by distributing the mechanical energy into the distal muscles during take-off phase of vertical jump. [9,10,11] The other hip extensor is the Hamstring which is a two joint muscle. In addition to extending the hip, Hamstrings is the strong knee flexors. The role of Hamstring is limited during vertical velocity take-off phase because the knee flexion is not important than the trunk flexion during early preparatory phase of vertical jump. This biomechanical factor supports our study observation of hip extensors that is during take-off phase, only GM would be recruited concentrically which help to distributes energy to distal muscles.

Several researches have reported that knee extensors are the most important contributor of vertical jump performance which also supports our study data. [35,21] The Vastus Medialis (VM), Vastus Lateralis (VL) and Vastus intermedius (VI) are reported to be the most important muscles for strong torque production during the velocity vertical take-off. The Rectus Femoris is another muscle of Quadriceps which is two joint muscle involved in hip flexion also. Because the take-off phase requires strong hip extension and not hip flexion, the role of Rectus Femoris is less active.

During the vertical jump take-off phase, the force production is primarily by 3 quadriceps muscles (VM, VL, and VI) and Hip extensors (GM). The role of ankle plantar flexors is to help out just before the feet leave the ground by addition of little force to the vertical take-off.

Brian R and coworkers reported the transfer of mechanical energy by two-joint muscles during vertical jump. [9] The Hamstring, the Rectus Femoris and The Gastrocnemius (GAS) are compared to act as stiff cable which connects the anterior (RF) and posterior part (Hamstring) of pelvis to distal femur and to the calcaneum (GAS). During the early take-off phase, the proximal GM concentrically contract resulting not only in the hip extension but also knee extension due to the pull of stiff cable (RF) acting on femur distally, thus transferring the mechanical energy generated by GM to Quadriceps through RF. The same phenomenon is also observed during knee extension and plantar flexors (GAS) acts as stiff cable which transfers the mechanical energy during the take-off phase.

Similar finding is reported by Daniel Gerald that hip extensors strength is most important during the eccentric phase, while knee extensor strength is most important during the concentric phase of vertical jump.

Another interesting finding was observed in our study that the subjects who scored ≥ 50 cm recorded strong concentric peak torque of knee extensors that the subjects who scored < 50 cm. This finding can be attributed to the anthropometric differences between the players. Rupesh Patel reported that leg length showed positive association with strong hip/ knee ratio during vertical jump. [36] While analysis the demographic data of subjects, it is evident that the subject who measured the best score on vertical jump was the tallest among all the subjects. Further to this, the size of a muscle may have implications to force production and vertical jump performance. A larger physiologic cross-sectional area (PCA) may reflect an increased number of sarcomeres present. This could result in a greater number of cross-bridge formations, which would increase force production. In vertical jumping, larger muscle size of quadriceps may have positive associated with jump performance. [37]

This investigation examined the relationship between concentric peak torque of hip extensors, knee extensors and ankle plantar flexors with vertical jump among basketball players. Since the development of force is an important determinant of the final jump height achieved [38] and strength is a measurement of force development in the lower limb muscles, so vertical jumping ability must be related to strength.

CONCLUSION

In conclusion, the result of this study indicates the significant correlation of peak torque of knee extensors at angular velocity of 120^{0} per sec with vertical jump performance among basketball players. The knee extensors seem to be the greater contributor for vertical jump performance. This information can be used as guidance for sports specific training of athletes to improve vertical jump performance.

Practical applications

From a practical point of view, to improve vertical jump in athletes, resistive training regime may include strengthening of knee extensors. Although the ability of vertical jump performance is the summation of force production from lower limb muscles, the knee extensors shown a greater contributor for better performance. Therefore, to improve maximum power related to vertical jump performance, velocity- strength training program with knee extensor is best.

Limitation of the study

1. Isokinetic assessment of lower limb muscles was measured at only one angular velocity.
2. Vertical jump test was not measured using vertec or force platform
3. Only male players were recruited.

List of Abbreviation

VJ : vertical jump
nm : newton's meter
RF : Rectus Femoris
GAS : Gastrocnemius
VM : Vastus Medialis
VL : Vastus Lateralis
VI : Vastus Intermedius

Competing Interests: The authors declare that they have no competing interests.

Authors contributions:

Kriti Singh- has contributed towards the conceptualization of the study and design, data acquisition and interpretation and drafting the manuscript for its intellectual content.

Soni Satish -Has played a role in conceptualization of the research idea,

supportive guidance throughout in execution of the study and in the critical and technical revision of the manuscript.

REFERENCES

1. Chi-yang tsai, Wei-hua ho, Yun-kung lii, Chin-linhuang. The kinematic analysis of basketball three point shoot after high intensity program. SAP. 2006;26:10:45
2. Meckell Y, Casorla T, Eliakim A. The influence of basketball dribbling on repeated sprints. International Journal of Coaching Science. 2009; 3(2):43–56.
3. Erculj F, Blas M, Bracic M. Physical demands on young elite European female basketball players with special reference to speed, agility, explosive strength, and take-off power. J Strength Cond Res. 2010; 24(11):2970–2978.
4. Cohen D, Anne D. Strength, Power, Speed, and Agility of Women Basketball Players According to Playing Position. The Journal of Strength and Conditioning Research. 2009;23(7): 1974-81.
5. Hess. Analysis of the Jump shot, Athletic Journal. 1980; 61(3), 30-33, 37-38, 58.
6. Bucher, C Wuest, D. Foundations of physical education, exercise science, and sport. McGraw-Hill Higher Education 2009.
7. Hay JG, Wilson BD, Andrews G, Woodworth GG. An analysis of joint contributions to the performance of a gross motor skill. Sixth International Congress of Biomechanics 1977; 64-70
8. Pandy MG .Seth A.A neuromusculoskel et al tracking method for estimating individual muscle forces in human movement. J Biomech. 2007; 40(2): 356-66.
9. Brain R, Umberger. Mechanics of vertical jump and two- joint: implication for training. Strength and conditioning 1998;20:70-74
10. Nongnapas Charoenpanich, Rumpa Boonsinsukh, Sirod Sirisup, Vitoon Saengsirisuwan. Principal component analysis identifies major muscles recruited during elite vertical jump. Science Asia 2013;39:257-264
11. Van ingenschenau. From rotation to translation: constraints on multi-joint movements and the unique action of bi-articular muscles. Human movement science 1989:8:301-337
12. Jan Babic, Jadran Lenarcic. Vertical Jump: Biomechanical Analysis and Simulation Study. Humanoid Robots: New Developments"2007
13. Frank I. Katch, William D. McArdle, Victor L Katch. Lippincott Williams & Wilkins, 1993
14. Bobbert MF. Casius LJ, Sijpkens IW, Jaspers RT. Humans adjust control to initial squat depth in vertical squat jumping. J Appl Physiol. 2008; 105(5):1428-40.
15. Chappell JD, Creighton RA, Giuliani C, Yu B, Garrett WE. Kinematics and electromyography of landing preparation in vertical stop-jump: risks for noncontact anterior cruciate ligament injury. Am J Sports Med. 2007;35(2):235-41
16. de Ruiter CJ, Vermeulen G, Toussaint HM, de Haan A Isometric knee-extensor torque development and jump height in volleyball players. Medical Science Sports Exercise.2007;39:1336–46.
17. Earp JE, Joseph M, Kraemer WJ, Newton RU, Comstock BA, Fragala MS. Lower-body muscle structure and its role in jump performance during squat, countermovement, and depth drop jumps. J Strength Condit Res 2010; 24: 722–9
18. Farias DL, Teixeira TG, Madrid B, Pinho D, Boullosa DA, Prestes J. Reliability of vertical jump performance evaluated with contact mat in elderly women. Clin Physiol Funct Imag.2013; 33:288–92.
19. Rittweger J, Schiessl H, Felsenberg D, Runge M Reproducibility of the jumping mechanography as a test of mechanical power output in physically competent adult and elderly subjects. J Am Geriatr Soc.2004;52:128–31
20. Canavan PK, Vescovi JD. Evaluation of power prediction equations: peak vertical jumping power in women. Med Sci Sports Exerc. 2004; 36:1589–93.
21. Hubley CL, Wells RP. A work-energy approach to determine individual joint contributions to vertical jump performance. European Journal of Applied Physiology.1983; 50:247-254.
22. Fukashiro S, Komi PV. Joint moment and power flow of the lower limb during the vertical jump. International Journal of Sports Medicine.1987; 8:15-21.
23. Vanezis A, Lees A. A biomechanical analysis of good and poor performers of the vertical jump. Ergonomics. 2005;48:1594-603
24. Norkin C, Levange P. Joint Structure and Function: A Comprehensice Analysis.

Philadelphia, F.A Davis 1983

25. Tibor Hortobagyi, Frank I. Katch Peter F. LaChance. Interrelationships among various measures of upper body strength assessed by different contraction modes. European Journal of Applied Physiology and Occupational Physiology 1989;(58)7:749–755
26. OddssonL, Westing SH. Jumping height can be accurately predicted from selected measurements of muscle strength and biomechanical parameters. In C. L. Tant, P. E. Patterson & S. L. York (Ed.), Proceedings of the Ninth International Symposium of the International Society of Biomechanics in Sports .1991;29-33
27. Hess GP, Cappiello WL, Poole RM, Hunter SC. Prevention and treatment of overuse tendon injuries Sports Med. 1989;8(6):371-84.
28. Panni A, Biedert RM, Maffulli N, Tartarone M, Romanini E. Overuse injuries of extensor mechanism in athletes. Clin Sports Med 2002;21:483-98.
29. Goran Markovic Does plyometric training improve vertical jump height? A meta-analytical review. British journal of sports medicine. 2007;41: 6
30. Wilson GJ, Newton RU, Murphy AJ, *et al*. The optimal training load for the development of dynamic athletic performance. Med Sci Sports Exerc 1993; 25:1279–86.
31. Malatesta D, Cattaneo F, Dugnani S, *et al*. Effects of electromyostimulation training and volleyball practice on jumping ability. J Strength Cond Res 2003;17:573–9
32. Cardinale M, Bosco C. The use of vibration as an exercise intervention. Exerc Sport Sci Rev. 2003;31:3–7
33. ErolKovacevic. Ensar Abazovic. Josipa Bradic. Mensur Vrcic.. The predictive value of isokinetic assessment on the explosive strength of the lower extremities. HomoSporticus2012;1
34. Tsiokanos, Athanasios, Kellis, Eleftherios, Jamurtas, Athanasios, Kellis, Spiros. The relationship between jumping performance and isokinetic strength of hip and knee extensors and ankle plantar flexors. Isokinetics and Exercise Science, 2002(10)2:107-115
35. Theoharopoulos, Anthony, Tsitskaris, George, Nikopoulou, Maria, Tsaklis, Panagiotis. Knee strength of professional basketball players. journal of strength & conditioning research. 2000
36. Rupesh Patel. Performance of a two-foot vertical jump: What is more important hip or knee dominance? Waterloo, Ontario, Canada, 2010
37. Davis DS, Briscoe DA, Markowski CT, Saville SE, Taylor CJ. Physical Characteristics that Predict Vertical Jump Performance in Recreational Male Athletes. Phys Ther Sport. 2003; 4(4):167–174.
38. Dowling J, VamosL. Identification of kinetic and temporal factors related to vertical jump performance. Journal of Applied Biomechanics.1993;995-110.

How to cite this article: Singh K, Satish S, Kumar SN. The relationship between vertical jump performance and peak torque of lower limb muscles among basketball players. Int J Health Sci Res. 2017; 7(7):117-128.

****