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Assessment of isokinetic muscle function in Korea male volleyball athletes

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Volleyball players performed numerous repetitions of spike actions, which uses and requires strong and explosive force, and control of the muscles of the shoulder, lower back, and legs. Muscle imbalance is one of the main causes of sport injuries. The purpose of this study was to assess isokinetic muscle functions in male volleyball players. We thus aim to accurately evaluate their muscle functions, and identify the best training strategy to achieve optimal muscle strength balance in future training programs. The participants in this study consisted of 14 male volleyball players. Muscle strength was measured using the isokinetic dynamometer. Muscle strength was evaluated in terms of peak torque and average power, calculated from five repeated measurements at an angular speed of 60°/sec. Three players who were left attackers showed shoulder imbalance, four players showed trunk joint imbalance, nine players had knee joint of extension/flexion imbalance and four players showed left/right imbalance. The results showed that the number of volleyball players with differences between the strength of the bilateral knee muscles, and between the strength of the hamstrings and quadriceps muscles was higher than the number of players with differences between the strength of the shoulder internal and external rotation muscles, and higher than the number of players with differences between the strength of the lower back extension and flexion muscles.

Keywords: Assessment, Isokinetic, Volleyball, Athletic

INTRODUCTION

Volleyball is a sport played in a relatively small court (9 m×9 m), inside which the players perform fast movement and repeated high vertical jumping in a very short time. During a volleyball match, the players are required to serve, pass, and set the ball, as well as to spike and attack. Among those actions, spiking and attacking demand intense vertical jumping and landing.

During volleyball matches, when numerous repetitions of the aforementioned movements are performed, the anaerobic type of exercise is the most frequently performed activity, with a ratio to aerobic exercises of 7:3 (Lamb, 1984). Playing volleyball also requires agility and fast reaction time in order to prevent the ball from touching the floor. A good muscle strength ratio between dominant and nondominant sides, and between antagonist and agonist muscles, especially of the knee joint, is ultimately important for sports in order to have stability of the lower limbs and to prevent knee injury (Agaard et al., 1998; Bahr and Krosshang, 2005). Since muscle imbalance is one of the main causes of sport injuries, the assessment of the muscle function is very important for designing injury prevention programs.

The hamstrings (flexion) and the quadriceps femoris (extension) muscles are the key effectors during high performance activities during sports, such as running and jumping (Jespersen et al., 2000). Most of the lower limb movements require strong bilateral muscle contractions (MacLaren, 1990). For volleyball it is important to have balanced muscle strength development in both legs (Brooks and Fahey, 1987; Thorstensson et al., 1976), with minimal differences regarding muscle strength between the dominant and nondominant legs. Further, the ratio between the muscle strengths of the hamstring and of the quadriceps (H/Q) should be low for volleyball.

Moreover, during a spike action, the muscles of the legs, lower back, and knees are used in an explosive manner in order to gener-

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ate a strong force, which requires effective control of the entire body in order to prevent injury. In other words, an ideal training method for volleyball would have to train the simultaneous control of the lower back, knees, and legs.

As it was previously reported, the spike and serving motions of volleyball require such dynamic stabilization in order to maintain the integrity of the glenohumeral joint (Aagaard and Jørgensen, 1996; Bahr and Krosshang, 2005). Stability of the glenohumeral joint during the acceleration, deceleration, and follow-through phases of striking is maintained by the rotator cuff muscles acting eccentrically, compressing the humeral head. Thus, active and passive mechanisms work to maintain dynamic stability and compression of the humeral head within the glenoid fossa during spiking and serving. A study by Aagaard et al. (1997) investigated knee injury in 295 Danish volleyball players and found that 55% of the players had experienced knee injury at least once, while 48% responded as having chronic knee injury. Players with 11.5 years of experience are in a group with increased risk of overuse injuries (Seminati and Minetti, 2013).

Further, a previous study showed that, for achieving good performances during powerful spikes and servings, cooperative harmony between the hamstrings, quadriceps, shoulder, and lower back muscles (Chung et al., 1987; Han et al., 2011). Specially, volleyball attackers exhibit increased risk for back injuries due to increased spinal twisting, flexing, lateral bending, and asymmetrical movements. In general, low back injuries are associated with dysfunctions regarding trunk muscle coactivation or recruitment patterns, not with reduced strength (Seminati and Minetti, 2013).

Isokinetic assessment can be used to measure torque values at several joint of the body. This assessment typically involves comparing the joint of interest with the corresponding contralateral joint. Isokinetic testing evaluates the torque generated during the exercise, allowing for an assessment of strength and functional ability, for a comparison of different muscles.

The objective of the present study was to assess isokinetic muscle functions in male volleyball players of the Korean national volleyball who is preparing for the 2020 Tokyo Olympics. We thus aim to accurately evaluate their muscle functions, and identify the best training strategy to achieve optimal muscle strength balance in future training programs.

MATERIALS AND METHODS

Participants

The participants in the present study consisted of 14 male volleyball players, aged 16–26 years, who are members of the Korean national volleyball team preparing for the Tokyo Olympics in 2020. The participants self-reported their play position, dominant leg and shoulder, length of their volleyball career, and age. Anthropometric measurements (Table 1) included height, body weight (BW), muscle mass, and body composition, and were performed using Inbody2 (Inbody 670, Seoul, Korea). The mean volleyball playing experience among the study participants was 103.14±39.6 months (range, 17–148 months). The mean height, weight, and age were 193.69±7.6 cm (range, 182.9–207.8 cm), 84.76±7.47 kg (range, 76.3–100 kg), and 20.7±1.8 years (range, 18–25 years), respectively.

Table 1. Baseline characteristics of the study participants (n=14)

No.	Height (cm)	Weight (kg)	Experience (mo)	Position
V1	192.2	85.2	120	L
V2	200	87.7	86	L
V3	186	84.5	96	L
V4	188	76.3	69	L
V5	191	82.3	122	R
V6	182.9	78.2	135	Li
V7	186.4	76.5	150	S
V8	194.8	85	125	R
V9	188.3	77.9	136	S
V10	201.9	100	41	C
V11	188.3	83.3	137	L
V12	207.8	99.8	84	C
V13	199.8	85.4	120	L
V14	203.2	82.6	17	L
Mean±SD	193.69±7.6	84.76±8.09	103.14±39.6	

The volleyball players' position codes are: C, center; L, left; Li, libero; R, right; S, setter. V, volleyball player; SD, standard deviation.

All participants had previously undergone isokinetic testing. They had no history of surgery of the knee, shoulder, or trunk. All measurements were taken regardless of injury status. Before testing, the participants completed a nonspecific, 5-min warm-up on a stationary bicycle ergometer at a self-regulated, low-to-moderate intensity, followed by 10 min of dynamic stretching that targeted the main muscle group being tested. The warm-up routine was performed under the supervision of a examiner.

Procedures

In the present study, muscle strength was measured using the isokinetic dynamometer (Cybex International Inc., New York, NY, USA) at the Department of Exercise Rehabilitation and Welfare, Gachon University. All measurements were performed by a examiner with 5 years of experience, during a single test session.

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Muscle strength was evaluated in terms of peak torque and average power, calculated from five repeated measurements at an angular speed of 60°/sec. To allow comparisons in terms of maximum muscle strength in the shoulder, knee, and lumbar joints, the peak torque was normalized by BW (PTBW, percent of torque produced per kg of BW).

Muscle strength in the shoulder was measured on the dominant side, while the shoulder's internal rotation and external rotation (peak torque, expressed in units of Nm) were measured for the striking arm, i.e., the shoulder that the participant reported to be using most frequently for hitting or serving the ball during the game (Stickley et al., 2008). The measurements were taken with the participants in a seated modified neutral position, with 90° of elbow flexion, 30° of glenohumeral joint flexion, and 30° of glenohumeral abduction; during the measurements, the participants wore stabilization straps across the hip and upper body.

The H/Q ratios for the right and left knee were measured on an adjustable dynamometer chair, with the participants comfortably seated with the hip joint at approximately 75° of flexion (where 0° represents full extension). The participants wore straps, and the shoulders were fixed in ventral-dorsal and cranial-caudal direction using shoulder pads. For further stabilization of the upper body during the test session, the participants were instructed to hold the handgrips located on the side of the chair. The measurement was taken with the participants performing concentric flexion and extension with their knees.

Trunk strength was measured between the 4th and 5th lumbar vertebrae, where the extension of the iliac crest meets the spine. Using this position as the reference, the footplate of the isokinetic dynamometer was adjusted to accommodate comfortable depth and height for each participant. The participants stood on the footplate, and pads were placed and fixed on the chest (below the clavicle), thighs, and below the knees. Subsequently, the participants were instructed to hold both handgrips located in front of their chest. The dynamometer used in our study was designed to enable trunk flexion and extension movements in an up-right position, with the feet positioned on two horizontal footplates, and the knees in a slightly flexed position (10°–20°). We measured trunk strength during trunk flexion from -10° to 50°, and during trunk extension from 50° to -10° (Davies and Gould, 1982; Guilhem et al., 2014).

Data analysis

The raw data for assessment and diagnosis of isokinetics and function of the shoulders, lower back, and knees were organized using Excel 2010 (Microsoft Corp., Redmond, WA, USA). The results are given as mean ± standard deviation and range.

RESULTS

Tables 2, 3, and 4 show the results regarding muscle strength of the shoulders, knees, and lower back in members of the male Korean national volleyball team preparing for the Tokyo Olympics in 2020.

With respect to the isokinetic muscle function in the shoulder, the lowest PTBW was noted for the athletes with the shortest volleyball experience (PTBW was 101 and 104 Nm/kg for participants V10 and V14, respectively), while the highest PTBW (149 Nm/kg) was noted for participant V13. When considering the playing position, the participants with highest PTBW values were V13 (PTBW = 143 Nm/kg), V12 (PTBW = 116 Nm/kg), and V8 (PTBW = 134 Nm/kg) for the left, center, and right position, respectively, while participant V7 had the highest PTBW (137 Nm/kg) among setters and libero players. Therefore, playing in the left position was associated with the highest PTBW of the shoulder, while playing in the center position was associated with the lowest PTBW. Participant V1 exhibited a low ratio (31%) between internal and external rotation of the shoulder, while participants V3 and V14 exhibited a high ratio (75% and 69%, respectively), suggesting muscle imbalance. Among these, only participant V3 reported having shoulder injury and associated shoulder pain.

With respect to the isokinetic muscle function in the lumbar joints, participant V4 had the lowest power (PTBW = 301 Nm/kg), while participant V4 had the highest power (PTBW = 468 Nm/kg). When considering the playing position, the participants with the highest PTBW were V4 (PTBW = 468 Nm/kg), V8 (PTBW = 456 Nm/kg), and V10 (PTBW = 402 Nm/kg) for the left, right, and center position, respectively, while participant V6 had the highest PTBW among setters and libero players (PTBW = 447 Nm/kg). Therefore, playing in the left position was associated with the highest PTBW of the lumbar joints, while playing in the center position was associated with the lowest PTBW. A total of 4 out of 14 participants (V4, V5, V8, and V11) exhibited a low ratio (< 80%) of extension and flexion in the lower back, suggesting muscle imbalance.

With respect to isokinetic muscle function in the knee, we found that the PTBW was generally higher in the right knee than in the left. Participant V4 had the highest PTBW (378 Nm/kg) of the right knee, while participant V10 had the lowest PTBV (148 Nm/kg). When considering the playing position, the participants

Table 2. Shoulder joint isokinetic muscle function assessment

Player's position	Rotation	Peak torque (Nm)	Peak torque/% BW (Nm/kg)	Average power per repetition (Nm)	Average power per repetition/% BW (Nm/kg)
V1 (L)	Internal rotation	114	137	90	108
	External rotation	35	42	23	29
	Ratio	31		26	
V2 (L)	Internal rotation	111	125	89	99
	External rotation	54	60	42	46
	Ratio	49		47	
V3 (L)	Internal rotation	98	116	79	92
	External rotation	73	86	51	59
	Ratio	75		65	
V4 (L)	Internal rotation	95	122	80	103
	External rotation	52	66	40	53
	Ratio	54		50	
V5 (R)	Internal rotation	107	131	90	110
	External rotation	58	72	38	46
	Ratio	54		42	
V6 (Li)	Internal rotation	100	128	87	112
	External rotation	58	75	44	57
	Ratio	58		51	
V7 (S)	Internal rotation	104	137	80	103
	External rotation	54	72	43	55
	Ratio	52		54	
V8 (R)	Internal rotation	113	134	92	110
	External rotation	66	77	57	68
	Ratio	59		62	
V9 (S)	Internal rotation	96	125	77	99
	External rotation	50	66	35	44
	Ratio	52		45	
V10 (C)	Internal rotation	100	101	79	81
	External rotation	50	51	32	33
	Ratio	50		41	
V11 (L)	Internal rotation	118	143	92	112
	External rotation	61	75	38	46
	Ratio	52		41	
V12 (C)	Internal rotation	117	116	96	97
	External rotation	62	63	43	44
	Ratio	53		45	
V13 (L)	Internal rotation	127	149	101	119
	External rotation	57	66	42	48
	Ratio	45		42	
V14 (L)	Internal rotation	87	104	69	81
	External rotation	60	72	45	53
	Ratio	69		65	
Total (mean)	Internal rotation	99.8	126.2	85.8	101.9
	External rotation	56.4	67	40.92	48.6
	Ratio	53.2		47.8	

The volleyball players' position codes are: C, center; L, left; R, right; S, setter.
BW, body weight; V, volleyball player.

with the highest PTBW were V4 (PTBW = 378 Nm/kg), V8 (PTBW = 313 Nm/kg), and V12 (PTBW = 250 Nm/kg) for the left, right, and center position, respectively, while participant V7 had the highest PTBW among setters and libero players (PTBW = 319 Nm/kg). Therefore, playing in the left position was associated with the highest PTBW, while playing in the center position was associated with the lowest PTBW.

Of the 14 participants, a total of 8 (V1, V2, V4, V5, V10, V12, V13, and V14) had left-right extension deviation of > 10%, while 4 (V1, V4, V7, and V13) had left-right flexion deviation. Moreover, considering that the normal extension and flexion ratio is 50%–70%, a total of 4 participants (V1, V5, V10, and V11), showed imbalance on the right side, while 5 participants (V1, V2, V5, V11, and V14) showed imbalance on the left side. Among these, there were two participants with PTBW of < 200 Nm/kg, specifically: participant V10 among center position players (PTBW = 149 Nm/kg), and participant V1 among left position players (PTBW = 188 Nm/kg).

DISCUSSION

Assessments of muscle strength have been conducted using various isometric, isotonic, and isokinetic exercise methods. It was suggested that isokinetic exercise using an isokinetic dynamometer allows for a more objective and accurate assessment (Hislop and Perrine, 1967) this was later proven by Thistle et al. (1967). During isokinetic exercise, which has a predefined exercise speed, when the muscle strength is too high, or the exercise speed exceeds the limit predefined in the machine, the machine applies a resistance force equivalent to the surpassing amount. This resistance force is considered to expresses the force generated in the muscles, and is stored in the machine as torque force. Moreover, unlike isometric or isotonic exercises, the isokinetic exercise has the advantage of generating maximum contraction for the entire range of motion (ROM) (Hislop and Perrine, 1967). Thus, isokinetic exercise can objectively and accurately compare the bilateral muscle strengths of a particular joint, as well as the agonistic and antagonistic muscle strengths of a single joint. Further, this technique also allows for evaluating the strength in relation to BW. Moreover, the exercise speed can be increased as the muscle strength increases in order to allow for a gradually increasing intensity during exercise and training (Gilliam et al., 1979; James et al., 2014; Kim and Youn, 2005; Rodríguez-Ruiz et al., 2014; Rosene et al., 2001).

The optimal ratio between internal and external rotation in the

Table 3. Knee joint isokinetic muscle function assessment

Player's position	Imbalance	Peak torque (Nm)			PT/ %BW (Nm/kg)		Average power per repetition (Nm)			APR/ %BW (Nm/kg)	
		R	L	Ratio	R	L	R	L	Ratio	R	L
V1 (L)	EX	155	89	57	188	107	104	61	60	125	75
	FLEX	122	107	88	146	128	91	80	89	110	97
	Ratio	79	120	-	77.6	119	88	131	-	88	129
V2 (L)	EX	205	156	76	229	176	126	103	82	141	116
	FLEX	140	129	92	158	143	105	91	87	119	101
	Ratio	68	83	-	69	81.2	83	88	-	84.4	87
V3 (L)	EX	235	240	98	277	283	138	152	91	163	180
	FLEX	134	137	99	158	161	92	98	94	108	116
	Ratio	57	57	-	56.6	57	67	64	-	66.2	64
V4 (L)	EX	290	217	75	378	283	193	147	76	251	191
	FLEX	186	145	78	241	188	126	106	84	165	138
	Ratio	64	67	-	64	66.4	65	72	-	66	72
V5 (R)	EX	217	119	55	265	146	146	92	63	178	112
	FLEX	170	153	90	206	188	120	110	92	147	134
	Ratio	78	128	-	78	128	82	120	-	83	119
V6 (Li)	EX	241	217	90	310	280	171	150	68	220	193
	FLEX	159	144	90	203	185	117	109	93	149	141
	Ratio	66	66	-	65	66	73	73	-	68	73
V7 (S)	EX	245	224	91	319	292	165	138	84	215	180
	FLEX	125	142	88	161	185	94	102	92	123	132
	Ratio	51	64	-	50.4	63.3	57	74	-	57	73
V8 (R)	EX	264	283	94	313	337	171	183	93	202	218
	FLEX	182	174	96	215	206	114	115	99	136	136
	Ratio	69	61	-	69	61	67	63	-	67	62
V9 (S)	EX	195	201	97	250	259	122	144	85	156	185
	FLEX	132	136	97	170	173	97	92	95	125	119
	Ratio	67	68	-	68	67	80	64	-	80.1	64
V10 (C)	EX	146	209	70	149	215	82	112	73	84	114
	FLEX	122	118	97	125	119	75	76	99	77	77
	Ratio	83	56	-	84	55	91	65	-	92	68
V11 (L)	EX	274	256	93	331	310	186	154	83	224	187
	FLEX	129	125	97	155	152	91	85	93	110	103
	Ratio	47	49	-	47	49	49	55	-	49	55
V12 (C)	EX	250	206	82	250	209	170	149	88	171	149
	FLEX	151	136	90	152	137	102	98	96	103	99
	Ratio	60	66	-	61	66	60	66	-	60	66
V13 (L)	EX	285	220	77	334	259	210	149	71	246	176
	FLEX	151	129	85	176	152	105	94	90	123	110
	Ratio	53	59	-	53	59	50	63	-	50	63
V14 (L)	EX	252	202	80	301	241	178	145	81	211	171
	FLEX	165	152	92	197	182	120	115	96	143	136
	Ratio	66	75	-	65	81	67	79	-	68	80
Total (mean)	EX	232.4	196.4	84.5	278.1	242.6	154.4	134.2	78.4	184.7	160.5
	FLEX	147.7	137.6	93.1	175.9	164.2	103.5	90.3	92.7	124.1	117
	Ratio	64.8	72.7	-	64.8	72.7	69.9	76.9	-	69.9	76.7

The volleyball players' position codes are: C, center; L, left; R, right; S, setter.
BW, body weight; EX, extension; FLEX, flexion.

Table 4. Trunk joint isokinetic muscle function assessment:

Player's position	Imbalance	Peak torque (Nm)	Peak torque/% BW (Nm/kg)	Average power per repetition (Nm)	Average power per repetition/% BW (Nm/kg)
V1 (L)	EX	335	405	218	264
	FLEX	358	432	288	347
	Ratio	106		7	
V2 (L)	EX	344	387	265	297
	FLEX	311	349	253	284
	Ratio	90		95	
V3 (L)	EX	296	349	228	270
	FLEX	282	334	232	275
	Ratio	95		98	
V4 (L)	EX	359	468	272	354
	FLEX	248	322	220	286
	Ratio	69		81	
V5 (R)	EX	317	384	251	303
	FLEX	228	274	180	218
	Ratio	72		72	
V6 (Li)	EX	347	447	235	325
	FLEX	293	376	235	301
	Ratio	84		93	
V7 (S)	EX	328	426	240	312
	FLEX	296	384	244	316
	Ratio	90		98	
V8 (R)	EX	384	456	232	275
	FLEX	273	325	226	268
	Ratio	71		97	
V9 (S)	EX	343	441	238	305
	FLEX	283	364	237	305
	Ratio	83		100	
V10 (C)	EX	395	402	231	235
	FLEX	389	396	285	292
	Ratio	99		81	
V11 (L)	EX	344	447	236	308
	FLEX	256	334	220	286
	Ratio	74		93	
V12 (C)	EX	382	384	278	281
	FLEX	366	370	300	303
	Ratio	96		93	
V13 (L)	EX	287	337	222	262
	FLEX	296	349	232	273
	Ratio	97		96	
V14 (L)	EX	252	301	201	240
	FLEX	292	346	223	266
	Ratio	86		90	
Total (mean)	EX	339.5	402.4	239	287.9
	FLEX	297.9	353.9	241	287.7
	Ratio	85.7		90.1	

The volleyball players' position codes are: C, center; L, left; R, right; S, setter.
BW, Body weight; EX, extension; FLEX, flexion.

shoulder was shown to be 3:2; the optimal ration between trunk flexion and extension was shown to be 1:1; and the optimal ratio between knee flexion and extension was shown to be 2:3 (Dvir, 2004; Rosene et al., 2001). However, the ranges of ideal muscle strength ratio vary depending on the study. For the knees, the ratio of forces involved in extension to those involved in flexion should be at least 50%–70%. Further, the force ratio between the dominant and nondominant sides should be of 1:1; however, a difference of 10% is considered as being within a normal range (Andrade Mdos et al., 2012; Cheung et al., 2012; Dirnberger et al., 2012; Elliott, 1978).

ROM used during trunk isokinetic testing varies depending on the study. Smith et al. (1985) used flexion range of 30°–40° and extension range of 15°–20°, while Kim and Shin (1999) and Newton et al. (1993) applied flexion range of 80°, and Davies and Gould (1982) applied a ROM of ≥90°. However, the most effective ROM for studying trunk muscle strength and trunk exercise has not been suggested yet. In the present study, ROM was set to 80° for flexion and 15° for extension, in order to induce peak isokinetic flexion and extension. All participants were able to perform the exercise relatively easily within these ranges. The angular speed used to measure trunk isokinetic strength depends on the study. Particularly, with respect to the speed of isokinetic trunk flexion and extension, Parnianpour et al. (1988) stated that trunk flexion and extension speed of 60°/sec is appropriate for activities of daily living, while a speed of 30°/sec is appropriate for patients with lower back pain (Marras and Wongsam, 1986); if lower back injury is incomplete, measuring at 60°/sec would not represent a fully functional activity. Newton et al. (1993) stated that the ideal measurement should account for the exercise speeds of 60°/sec, 90°/sec, and 120°/sec. In the present study, the speed was set to 60°/sec for measuring the maximum muscle strength of the volleyball players.

There have been many studies on the extension and flexion strength of the trunk muscles, and the reported results have indicated that extension was stronger than flexion (Flint, 1958; Guilhem et al, 2014; Mayer et al., 1985; McNeill et al., 1980; Smidt et al., 1980). The reason for this is that the cross section during trunk extension is bigger than during flexion. Therefore, although the trunk extension to flexion ratio is known to be from 1.1:1 to 2.7:1 (Dvir, 2004; Smith et al., 1985; Wessel et al., 1992), in the case of volleyball players, at the moment of bending the lower back backwards and engaging in position for spiking or serving, maximum power is generated by the combination of power from flexion motion of the lower back and of the shoulders. Therefore, it would be possible to assume that the appropriate flexion to extension ratio for preventing lower back injury and for drawing out peak sports performance would be 1:1. However, the results of the present study showed that 13 of the 14 players exhibited greater strength for extension than for flexion. Moreover, results from measurements of 5 repetitions performed at the speed of 60°/sec showed that 4 of the 14 players had a difference of ≥20% in the trunk flexion-to-extension ratio, showing a relative imbalance regarding the strengths for extension and flexion. This result supports the need for training programs focused on balance control. In order to understand which ratios would allow for better spike and serving skills during matches, studies on reference values for PTBW and extension and flexion strength ratio are needed. Most volleyball players use one arm the dominant to practice a lot of forceful spike and overhead serves during the training season.

Bahr and Krosshaug (2005) indicated that muscle imbalance causes damages to the joints by pulling down on the joints in an asymmetric manner (Meister and Andrews, 1993). Based on this, it is possible that having unbalanced internal to external rotation ratios is associated with higher risk of injury. Chung et al. (1987) compared the external and internal rotation muscle strengths of healthy Korean adults and found that the muscles responsible for internal rotation had higher strength than those responsible for external rotation. The results of Mayer et al. (1994) indicated that normal ratios of external to internal rotation strengths for the general population for 60°/sec testing were 0.57 for the dominant side and 0.61 for the nondominant side in a concentric test. Wang et al. (2000) measured shoulder muscle strength of players on the English national volleyball team and found that the ratio of strength of the external rotator to that of the internal rotator muscle were approximately 1 for the dominant side and 0.67 for the non-dominant side in a concentric test.

In the present study, the difference in shoulder internal and external rotation ratio was 53.2%, with internal rotation showing. Imbalance in shoulder internal-to-external rotation strength ratio was observed in 3 of the 14 players. In the results of the present study and in those of precedent studies, internal-to-external rotation strength ratios of volleyball players' shoulders were 3:2 for the dominant side, but 1:1 for the nondominant side. Accordingly, studies regarding internal and external rotation ratios are warranted in order to facilitate the prevention of shoulder injuries. Further, such studies, when focused on game performance, could help identify the minimal value of PTBW required for performing volleyball actions such as powerful spike and serving (James et al., 2014; Wang et al., 2000).

The major agonistic muscles recruited for those movements are the hamstrings and the quadriceps, with the back of the legs and the tibialis anterior also serving as contributors. Moreover, for spike actions, a greater coordination between the major back muscles and the muscles of the shoulder area must be achieved (Reeser et al., 2006; Seminati and Minetti, 2013)

Imbalance signifies possible additional risk, such as soft tissue damage, regardless of the various causes of injury (Zakas et al., 1995). Of course, there are limitations in relating the isokinetic muscle strength, measured mechanically, to the possibility of injury in an actual match or during practice situations. However, in the field of sports medicine, this relation is commonly very high. In particular, Aagaard et al. (1998) claimed that having an isokinetic muscle strength ratio of ≤60% at low angular speed increased the risk of injury, while Ayala et al. (2012) reported that increased quadriceps strength from training can reduce activation of antagonistic muscles of the hamstrings. Such low isokinetic balance ratio can be a cause of increased risk of knee injury by exerting tensional stress on the anterior cruciate ligament due to a decrease in joint stabilizing muscle strength (Cheung et al., 2012; Rosen et al., 2001).

Three out of 14 players had a shoulder flexion-to-extension ratio of 2:3. When considering the knees, shoulders, and lower back, the region for which the highest number of players exhibited imbalance was the knee joints. Players of the left position exhibited the highest peak torque values for the shoulders, knees, and lower back, while players of the center position exhibited the lowest peak torque for all regions. In a study by Chae et al. (2002), the mean knee kinetic 60°/sec PTBW of volleyball players who play on attacking positions was 329, while those of setters and libero players were 310 and 314, respectively. However, in the present study, left side attackers exhibited a PTBW of 291, while the highest value of PTBW was 378, for the participant V4, which indicates significant variation among attackers.

In a study by Kim and Choi (2007), the national team players showed normal reference values, with a PTBW of 270, left-right deviation of <10%, and an extension/flexion ratio of 55%. In the present study, 8 out of 14 participants had left-right deviation ≥10%, while 4 out of 14 had muscle imbalance (i.e., an extension/flexion ratio outside the range 50%–70%). We may conclude that the volleyball players included in the present study should undergo a rehabilitation program to recover from knee injury.

Participating in elite sports competitions requires continuous, quantitative improvement in the angular torque and angle for which maximum muscle strength is manifested, as these parameters allow superior execution of actions during which maximum muscle strength needs to be generated quickly. The underlying mechanisms were proposed by Thorstensson et al. (1976), and involve force, muscle contraction speed, and muscle fiber relationships. Specifically, the maximum force generated depends on the number and type of muscle fibers recruited, as well as on the speed and cooperativity of nerve impulses. Moreover, recruitment of the nerve-muscle unit is very important for increasing the efficiency of movement, and this is reported to be highly associated with the angle at which maximum muscle strength is manifested (Moffroid et al, 1969). Taken together, these results suggest that the angle at which maximum muscle strength is manifested plays a very important role in sports performance. Together with maximum muscle strength, this angle affects mean power and muscle endurance. Since power represents the value of work divided by time, muscle strength (i.e., force) must be increased above all others, and must be generated in the initial stage of the effort in order to achieve increased power. In the present study, an isokinetic dynamometer was used to assess the shoulder, lower back, and knee muscle functions of male players of the Korean national volleyball team. The results showed that the number of volleyball players with differences between the strength of the bilateral knee muscles, and between the strength of the hamstrings and quadriceps muscles was higher than the number of players with differences between the strength of the shoulder internal and external rotation muscles, and higher than the number of players with differences between the strength of the lower back extension and flexion muscles. These findings may suggest that the risk of knee injury is greater than that of shoulder or lower back injury. With respect to player positions, players who play in the center position exhibited the lowest muscle function for all the 3 studied categories (shoulders, knees, and lower back). Future studies are warranted to research the reference values of optimal PTBW, which can be used for injury prevention and for executing powerful spikes and servings.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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