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ORIGINAL

Evaluation of Biomechanical Movements and Injury Risk Factors in Weight Lifting (Snatch)

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Objective: The purpose of this study was to investigate the possibility of injuries and the types of movement related to damage by body parts, and to prepare for prevention of injuries and development of a training program.

Method: For this study, the experiment was conducted according to levels of 60 percentages (ST) and 85 percentages (MA) and 10 subjects from the Korean elite national weightlifting team were included. Furthermore, we analyzed joint moment and muscle activation pattern with three-dimensional video analysis. Ground reaction force and EMG analyses were performed to measure the factors related to injuries and motion.

Results: Knee reinjuries such as anterior cruciate ligament damage caused by deterioration of the control ability for the forward movement function of the tibia based on the movement of the biceps femoris when the rectus femoris is activated with the powerful last-pull movement. In particular, athletes with previous or current injuries should perceive a careful contiguity of the ratio of the biceps femoris to the rectus femoris. This shows that athletes can exert five times greater force than the injury threshold in contrast to the inversion moment of the ankle, which is actively performed for a powerful last pull motion and is positively considered in terms of intentional motion. It is activated by excessive adduction and internal rotation moment to avoid excessive abduction and external rotation of the knee at lockout motion. It is an injury risk to muscles and ligaments, causing large adduction moment and internal rotation moment at the knee. Adduction moment in the elbow joint increased to higher than the injury threshold at ST (60% level) in the lockout phase. Hence, all athletes are indicated to be at a high risk of injury of the elbow adductor muscle. Lockout motion is similar to the "high five" posture, and repetitive training in this motion increases the likelihood of injuries because of occurrence of strong internal rotation and adduction of the shoulder. Training volume of lockout motion has to be considered when developing a training program.

Conclusion: The important factors related to injury at snatch include B/R rate, muscles to activate the adduction moment and internal rotation moment at the elbow joint in the lockout phase, and muscles to activate the internal rotation moment at the shoulder joint in the lockout phase.

Keywords: Weightlifting, Moment, Snatch, Injury

INTRODUCTION

Currently, China dominates in the sport of weight lifting, which was previously dominated by Europeans countries, owing to its established operational system that involves 22 provinces, 4 metropolitan cities, and 5 autonomous districts, as if nurturing a national weight lifting team for the country from each municipality by selecting and training potential athletes, and creating a provincial representative system. Along with systematic technical establishment, China has secured a large pool of talented athletes and has trained top athletes selected through competition, all of which are believed to have contributed to this outcome. However, other nations are experiencing a gradual decrease in the size of their weight lifting populations and are faced with operating their national teams with limited athlete infrastructure and a small pool of athletes. The South Korean national weight-lifting team has only 1 or 2 athletes capable of winning an Olympic medal. Moreover, the team consists of many athletes who continue to train while persevering through pain from injuries. Weight lifting is one of the sports with high injury rates. The reason for this is that as compared with other sports, weight lighting involves lifting heavy weights above one's head and the slightest improper motion can directly place a heavy burden on the joints and ligaments, which can be closely linked to injuries. Mundt et (1993) reported that the sport of weight lifting can cause minor muscle tissue injuries and other major injuries, including spondylolysis and meniscal injuries. As such, it is closely associated with minor and major injuries. Studies on injuries in weight lifting include a study by Stone et al. (1994), which reported that most injuries in weight lifting occur in the order of the knee, shoulder, and low back in terms of incidence rate, while among knee injuries, patellar tendinitis was the most common (DeHaven, 1986). Moreover, Calhoon and Fry (1999) reported that the typical injury among elite weight lifters was overuse injuries. Siewe et al. (1999) indicated that among the injuries incurred by weight lifters, ankle injuries accounted for 6.5%. Meanwhile, Fong et al. (2012) stated that most ankle injuries were inversion injuries, and Moon, Jung and Chung (1995) reported that ankle injuries occurred from the motion generated when lowering the barbell after it was fully lifted. Kulund, Dewy and Brubaker (1978) mentioned that during the lockout motion, the motion of dropping the barbell backward generates extreme external rotation and flexion in the shoulder joints to cause should injuries, while Gregg and Andrew (1999) reported that most injuries in weight lifting occurred in the lower back, knees, and shoulder area, with strains and tendinitis accounting for 68.9% of all injuries, and acute and chronic injuries accounting for 59.6% and 30.4%, respectively. In addition to these studies, many other studies have been conducted on injuries in weight lifting, but those studies were not detailed and merely cross-sectional studies limited to investigating injured areas or statistical comparisons of moment values, and failed to link snatch motion in providing information associated with cause of injury and injury threshold levels. Accordingly, the objective of the present study was to provide important information for the development of injury prevention and revised training programs by identifying the possibility of injury and types of motion associated with injury according to progression to motion during execution of a snatch motion.

METHODS

To identify the possibility of injury and types of motion associated with injury according to progression to motion during execution of a snatch motion, analysis was performed on the techniques and force used during snatch motion in national team weight lifters (7 men and 3 female weight lifters; Table 1).

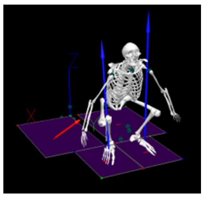
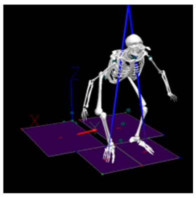
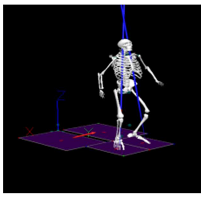
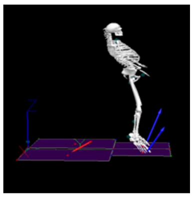
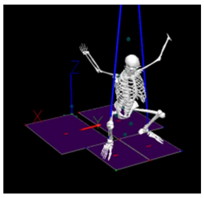
To identify injury motion and injury-related factors, joint moment and joint force were calculated by using 3-D image analysis, ground reaction force (GRF) analysis, electromyographic (EMG) analysis, and the Visual 3D analysis program (Moon & Chun, 2013). For the experiment with each athlete, an infrared real-time motion analyzer from Motion Analysis was used to perform a 3-D motion analysis with a sampling rate of 120 Hz, while a force plate from Kistler with a sampling rate of 1,200 Hz was used to acquire the data for GRF analysis. EMG analysis was performed with a sampling rate of 1,000 Hz, analyzing the pattern of EMG activities in the biceps femoris and rectus femoris, which represent an antagonistic muscle pair in the left and right lower extremities (Moon, Lee & Lim, 2006). From each athlete, the best motion at the 60% level of personal best record (snatch motion performed best with adequate amount of weight, as selected by the athlete and coach: ST) was acquired once. After 5 repeated measurements at around 95% level of best physical condition during the experiment (85% level of personal best record: MA), the best motion selected by the athlete and coach was used. In the EMG analysis, after the raw data were filtered, the data were normalized by considering the mean value from each trial to be 100%, while for the joint moment values (Mx, My, and Mz), the measured data were normalized by body weight. For investigation of injury threshold and diagnostic method for the possibility of injury, the possibility of injury was diagnosed based on joint moment data for injury diagnosis from a general mechanical perspective. Instead of a statistical analysis, analysis and discussion were conducted according to the characteristics and motion of each athlete. In detail, the ankle injury threshold was an inversion torque of 34.1 ± 14.5 Nm as reported by Parenteau, Viano and Petit (1998), and 35.1 ± 15.6 Nm as reported by Begeman, Balakrishnan and King (1993). The knee injury moment threshold was an internal/external rotation torque of 35~80 Nm and an abduction/adduction torque of 125~210 Nm as reported by Piziali, Nagel, Koogle

Table 1. Characteristics of the study subjects

Subject	Age (y)	Sex	Height (cm)	Body weight (kg)	Carrier (y)	Injury experience
S1	24	M	157	64	10	–
S2	34	M	155	56	21	–
S3	26	M	182	125	10	R. knee
S4	20	M	160	71	7	-
S5	33	M	189	144	19	R. knee
S6	18	M	183	131	10	Scaphoid fracture
S7	30	M	168	82	18	–
S8	20	W	158	71	5	–
S9	18	W	170	99	5	R. knee
S10	21	W	171	109	10	R. shoulder R. knee
Mean ± SD	24.4 ± 6.1	–	169.3 ± 12.1	95.2 ± 30.9	11.5 ± 5.8	–

M: man, W: woman, R: right

Table 2. Definition of events and phase

Event 1	Event 2	Event 3	Event 4	Event 5
				
Start	Barbell knee position	Barbell hip position	Maximal heel lift	lock out position
Phase 1		Phase 3		
	Phase 2		Phase 4	

and Whalen (1982). With respect to the elbows, the threshold was an internal rotation torque of 67 Nm and a varus torque of 64 Nm (64~120) as reported by Fleisig (1995). For in-depth analysis, events and phases were defined as shown in Table 2. Limited nalysis performed from phase 2 to 4 was a limitation in this study.

RESULTS

1. EMG analysis of the ratio between the biceps femoris and rectus femoris (*B/R* ratio)

In Table 3, With respect to the ratio between the biceps femoris and rectus femoris (*B/R* ratio), the S1 athlete showed a *B/R* ratio of 239% in phase 1 (P1) of ST (best executed motion at 60% level), which showed a difference greater by 51% than that of MA (motion executed at 85% level of the personal best record and ≥95% level of the best physical condition during the experiment). Similar to the S1 athletes, the S7 athletes showed a *B/R* ratio of 180% and 181% on the left and right sides during ST, respectively, whereas the values during MA were 19% and 54% on the left and right sides, respectively, exhibiting a phenomenon of reduced use of biceps femoris when the barbell was heavier. This type of phenomenon also appeared in S2 and S3 as well. On the other hand, S9 and S10 athletes showed higher values in P1 of MA when the barbell weight was heavier. In phase 3 (P3), the S1 athletes showed a large difference in ratio between ST (247%) and MA (23%). An interesting point was that the S6 athletes showed greater activation of the biceps femoris than of the rectus femoris, with values of 528% during ST and 384% during MA on the left side in P3. Meanwhile, the S3 and S10 athletes who had a history of knee injury showed relatively low biceps femoris activities on the right side in P3 of MA, with a *B/R* ratio of 27% and 55%, respectively.

2. Analysis of moments generated in the joints

In P3, S4 showed higher ankle inversion moment values of 128% (91 Nm) and 235% (167 Nm) on the left and right sides during ST, respectively, and 174% (123 Nm) and 217% (154 Nm) on the left and

Table 3. Ratio between the biceps femoris and rectus femoris

(unit: %)

Subjects		ST				MA			
		P1	P2	P3	P4	P1	P2	P3	P4
S1	R	154	122	115	53	101	106	24	131
	L	239	130	247	58	51	148	23	75
S2	R	132	135	233	54	111	88	74	14
	L	105	113	85	50	74	205	186	39
S3	R	111	105	188	102	50	81	27	161
	L	92	68	157	526	67	85	76	50
S4	R	90	152	67	185	79	52	70	142
	L	173	120	79	106	127	73	221	109
S5	R	39	24	34	281	92	66	215	62
	L	48	41	45	197	70	30	70	55
S6	R	273	207	51	92	112	29	265	143
	L	89	146	528	108	86	68	384	133
S7	R	181	141	78	75	54	118	81	82
	L	180	84	98	65	19	166	95	74
S8	R	105	157	69	80	131	62	51	148
	L	96	187	77	132	124	88	48	122
S9	R	97	53	156	146	135	104	103	109
	L	90	86	270	132	448	104	220	81
S10	R	89	152	78	91	232	61	55	60
	L	65	68	84	233	234	74	63	97
Mean (SD)	R	127 (64)	125 (52)	107 (65)	116 (70)	110 (51)	77 (27)	97 (80)	105 (48)
	L	118 (59)	104 (43)	167 (147)	161 (141)	130 (126)	104 (52)	139 (112)	84 (31)

R: right, L: left

Table 4. Maximal moment at phases 3 and 4 (unit: % [Nm])

Variables				S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean (SD)
P 3	A*I	ST	L	1	25	89	128	54	90	17	119	93	107	72 (44)
				(1)	(14)	(112)	(91)	(78)	(118)	(14)	(85)	(92)	(116)	72 (45)
			R	28	283	150	235	178	145	32	119	124	52	135 (83)
				(18)	(158)	(187)	(167)	(256)	(190)	(26)	(84)	(122)	(57)	127 (78)
		Ma	L	4	19	99	174	139	107	32	7	121	83	78 (59)
				(2)	(11)	(124)	(123)	(200)	(140)	(26)	(5)	(120)	(91)	84 (68)
			R	3	194	191	217	212	171	38	159	171	100	146 (74)
				(2)	(109)	(239)	(154)	(306)	(224)	(31)	(112)	(170)	(110)	146 (93)
P 4	A*E	ST	L	167	0	82	191	171	61	115	136	79	0	100 (68)
				(107)	(0)	(102)	(136)	(246)	(80)	(94)	(97)	(78)	(0)	93 (69)
			R	55	0	47	130	100	53	107	61	18	0	57 (44)
				(35)	(0)	(58)	(93)	(144)	(69)	(87)	(43)	(18)	(0)	54 (45)
		Ma	L	288	189	109	323	179	185	122	417	166	44	202 (110)
				(184)	(106)	(136)	(229)	(258)	(242)	(100)	(296)	(164)	(48)	176 (79)
			R	47	146	88	166	151	133	111	156	150	12	115 (51)
				(30)	(82)	(110)	(118)	(218)	(174)	(91)	(110)	(148)	(13)	109 (61)
	A*Ad	ST	L	113	180	16	57	40	22	14	15	42	34	53 (53)
				(72)	(101)	(20)	(40)	(58)	(29)	(12)	(10)	(42)	(37)	42 (28)
			R	142	328	26	1	6	17	1	31	20	31	60 (102)
				(91)	(91)	(33)	(0)	(9)	(22)	(1)	(22)	(20)	(34)	32 (33)
		Ma	L	121	25	45	66	58	39	14	8	54	13	44 (33)
				(77)	(14)	(56)	(47)	(84)	(51)	(11)	(6)	(54)	(15)	41 (28)
			R	118	209	61	69	53	122	16	105	66	48	86 (54)
				(76)	(117)	(76)	(49)	(77)	(160)	(13)	(75)	(66)	(53)	76 (39)
	K*Ad	ST	L	44	55	35	29	109	30	92	105	115	160	77 (44)
				(28)	(31)	(44)	(20)	(157)	(40)	(75)	(75)	(114)	(174)	75 (55)
			R	222	401	42	154	200	136	117	160	69	162	166 (98)
				(142)	(225)	(53)	(109)	(287)	(178)	(96)	(113)	(68)	(176)	144 (72)
		Ma	L	151	50	129	93	153	145	120	190	216	107	135 (47)
				(97)	(28)	(161)	(66)	(220)	(190)	(98)	(135)	(214)	(116)	132 (63)
			R	302	298	107	204	263	248	145	217	252	138	217 (68)
				(193)	(167)	(134)	(145)	(379)	(324)	(119)	(154)	(249)	(150)	201 (88)
	S*Ad	ST	L	232	287	246	360	264	113	220	34	293	93	214 (102)
				(148)	(161)	(308)	(255)	(380)	(148)	(180)	(24)	(290)	(101)	199 (107)
			R	280	284	137	228	274	129	129	42	208	101	181 (85)
				(179)	(159)	(171)	(162)	(394)	(169)	(105)	(30)	(206)	(110)	168 (93)
		Ma	L	193	322	298	464	388	195	230	112	447	163	281 (122)
				(123)	(180)	(373)	(329)	(559)	(255)	(188)	(80)	(442)	(178)	270 (152)

Table 4. Maximal moment at phases 3 and 4 (Continued) (unit: % [Nm])

Variables				S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Mean (SD)
P 4	S*Ad	Ma	R	270	333	165	359	424	217	301	120	320	227	273 (92)
				(173)	(187)	(206)	(255)	(610)	(284)	(247)	(85)	(317)	(248)	261 (138)
	E.*IR	St	L	36	91	84	111	105	121	105	32	65	40	79 (33)
				(23)	(51)	(104)	(78)	(151)	(159)	(86)	(23)	(65)	(43)	78 (48)
			R	30	329	154	98	92	91	93	37	116	25	106 (87)
				(19)	(184)	(192)	(69)	(132)	(119)	(76)	(27)	(114)	(27)	96 (63)
		Ma	L	60	199	202	170	195	190	106	145	203	51	152 (59)
				(39)	(111)	(252)	(121)	(280)	(249)	(87)	(103)	(201)	(55)	142 (88)
			R	79	139	152	125	117	157	68	109	97	76	111 (31)
				(51)	(78)	(190)	(89)	(169)	(206)	(56)	(77)	(96)	(83)	109 (56)

Note. A*I: Ankle inversion moment, A*E: Ankle extension moment, A*Ad: Ankle adduction moment, K*Ad: Maximum knee inversion moment, S*Ad: Shoulder adduction moment, E*IR: Elbow internal rotation moment

right sides during MA, respectively. By contrast, S1 showed very low inversion moment of 1% (1 Nm) and 28% (18 Nm) on the left and right sides during ST, respectively, and 4% (2.66 Nm) and 3% (2.06 Nm) on the left and right sides during MA, respectively, which indicated lower ankle activities than the other athletes. Meanwhile, no significant differences in mean values were found between ST and MA, but some athletes showed significant differences between their left and right feet (Table 4). In P4, S4 athletes expressed the highest ankle extension moment of 191% (135 Nm) in the left foot during ST, while S2 and S10 expressed the lowest values of 0.2% (0.11 Nm) and 0.03% (0.03 Nm), respectively, indicating a large difference among athletes for individual motion executed. In ankle adduction moment, although most athletes showed low values, S1 and S2 generated large adduction moments of 112% (72 Nm) and 180% (100 Nm), respectively, in their left feet during ST. In other words, S1 and S2 athletes appeared to generate greater adduction moment than other athletes to prevent excessive abduction from occurring during lockout. With respect to knee adduction moment, the mean values found on the left side was 77% (75 Nm) during ST and 135% (132 Nm) during MA, while the mean value on the right side was 166% (144 Nm) during ST and 217% (201 Nm) during MA, which indicated that the values increased as the barbell weight increased. Moreover, S2 also showed a large knee adduction moment value of 401% (224 Nm) on the right side during ST. With respect to shoulder adduction moment, the values from the left and right shoulders were 214% (199 Nm) and 181% (168 Nm) during ST, respectively, and 281% (270 Nm) and 273% (261 Nm) during MA, respectively, showing higher adduction moment values as the weight increased. However, the difference between the left and right shoulders appeared smaller during MA than during ST. With respect to elbow internal rotation moment, compared with than the other athletes, the S2 and S9 athletes showed a higher value of 328% (184 Nm) on the right side during ST and 203% (201 Nm) on the left side during MA, respectively. The mean values were 79% (78 Nm) and 106% (96 Nm) on the left and right sides during ST, respectively, and 152% (149 Nm) and 111% (109 Nm) on the left and right sides during MA, respectively, indicating that higher elbow internal rotation moment was generated as the barbell weight increased.

DISCUSSION

With respect to the *B/R* ratio, S1 and S7 athletes showed relatively higher values during ST than during MA in P1, whereas in P2, they showed higher values during MA, which demonstrated the phenomenon of decreased use of the biceps femoris with a higher barbell weight. This is believed to be attributed to the fact that during the start event, when the weight lifted is heavy, with the addition of more weight, the ratio of the agonistic muscle, rectus femoris, or gastrocneimus muscle becomes larger relative to the biceps femoris, which plays the role of an antagonistic muscle. Thus, it can become a cause of injury in the antagonistic muscle. In actual weight lifting, biceps femoris rupture occurs often during start position. We suspect that for these reasons, such injury occurs because the biceps femoris is less active or weaker than the rectus femoris. In P3, S2 athletes showed that the *B/R* ratio in the left foot became higher during MA than during ST, as the barbell weight increased, while the ratio in the right foot became lower. By contrast, S6 athletes showed a lower ratio in the left foot and a higher ratio in the right foot. Therefore, as some athletes showed discrepant ratios between the agonistic and antagonistic muscles or large differences, close attention should be paid on executing balanced motions or making sure the muscle ratio is consistent. It is interesting that among the athletes with a history of right knee injury, S3 and S10 showed very low ratios of 27% and 55%, respectively, in P3 of MA when the barbell weight was heavy. Therefore, these athletes possessed relatively weaker biceps femoris, which reduced their ability to control the forward movement of the tibia relative to the femur during weight lifting, as mentioned by Boden (2000), or that attempting to control the motion that generate knee hyperextension, such as the last pull motion in P3, may present inherent potential for recurrence of ACL injury. Moreover, Ostering (1986) reported that, normally, the ratio of the knee joint relative to the femoral joint is 60% and that when this ratio becomes ≤50%, the possibility of injury increased. Based on this finding, strengthening of the biceps femoris, the antagonistic muscle, is determined to be especially needed. Therefore, having low *B/R* ratios when executing the start motion with exertion of maximal muscle force and the last pull motion, when the barbell is lifted above the head with the most explosive force, is believed to be closely associated with short- and long-term injuries. Thus, attention should focus on the balance between the muscles that are involved in the flexion and extension of the lower extremities. According to Behm (1993), antagonistic muscle strengthening training relative to agonistic muscle is an important element in injury prevention mechanism. As such, it is believed that for weight lifters, focus should be placed on antagonistic muscle training in those with low *B/R* ratio in the lower extremity extensors.

With respect to joint moment analysis, most of the athletes showed imbalance between the left and right sides in maximum knee external rotation moment in P2 as the weight increased. This is believed to have occurred from imbalance in the left-right motion. To enhance the balance in motion, adjustment training is necessary, starting with light weight lifting. In particular, S4 athletes showed a knee rotation/abduction external rotation moment 20~120 Nm higher than the injury threshold of 35~80 Nm as suggested by Piziali et al. (1982). As the threshold levels suggested in the precedent studies came from cadaveric studies, the weight lifters showed values that exceeded the injury threshold level from being highly trained athletes with strong muscles and other bodily tissues. However, the fact that the knee external rotation moment generated in P2 exceeding the suggested injury threshold level is associated with the possibility of injuries is something that should be scrutinized. In P3, strong extension and inversion of the ankles and extension of the knees are performed to execute the last pull motion. S4 athletes showed high ankle inversion moment values of 128% (91 Nm) and 235% (167 Nm) in the left and right sides during ST, respectively, and 174% (123 Nm) and 217% (154 Nm) on the left and right sides during MA, respectively. The values were about 5 times higher than the injury threshold of 35.1 ± 15.6 Nm suggested by Begeman et al. (1993). This requires attention to make sure an even bigger value is not generated. An inversion moment represents the value expressed when a weight lifter, who has greater muscle strength than normal people, performs a dynamic motion. The fact that a large moment was expressed for a stronger last pull can be viewed positively, rather than as a cause of injury. In P4, a lockout is executed, which involves sudden concentration of load in the early stage of P4 as the barbell drops after being lifted to its peak height beyond the last pull. To withstand the vertical drop of the barbell, large ankle extension and knee extension moments are expressed. S4 athletes expressed the largest ankle extension moment, while S2 and S10 athletes expressed the smallest moment. This phenomenon may be due to differences in motion characteristics between the athletes, which can be attributed to receiving the barbell smoothly via a good balance between the weight lifter's posture and an appropriate barbell height after the last pull motion, or generating a large value from having a poor balance between posture and barbell height. Meanwhile, S2 showed a large knee adduction moment of 401% (224 Nm) in the right side of ST, which was a larger value than the knee adduction injury threshold of 125~210 Nm reported by Piziali et al. (1982). Moreover, S1 showed a left knee internal rotation moment of 138% (88 Nm) during ST and 291% (186 Nm) during MA, which exceeded the threshold level of 35.80 Nm reported by Piziali et al. (1982). As this phenomenon represents muscle expression under the situation of receiving the barbell as it drops after the last pull motion, which is largely passive in nature, and knee adduction and internal rotation moments expressed to control the motion of passive hyper-abduction and hyper-external rotation of the feet caused by the weight of the barbell. Therefore, the possibility of injury would be high in the muscle group that generates knee adduction moment, as the posture to execute lockout in P4 is assumed, which further requires training for assuming stable and balanced posture that can prevent such load being exerted unevenly to one side. In particular, when combined with valgus, internal rotation moment has been reported to be a primary cause of knee injuries such as ACL or PCL injuries (Kanam, Zeminski & Rudy, 2002), which warrants careful observations. In the shoulder internal rotation moment, the internal rotation moment in the left shoulder was 186% (179 Nm) during ST and 251% (240 Nm) during MA. In the right shoulder, the values were 181% (177 Nm) during ST and 270% (265 Nm) during MA, indicating larger moments during MA. This phenomenon is due to the fact that when the barbell becomes slanted more toward the back during squat lockout, even slightly, large external rotation is generated in the shoulder of the athlete. To suppress and offset this motion, the shoulder is forced to generate a large internal rotation moment. In addition, large mobility in the shoulder can increase this phenomenon. Gross, Brenner, Esformes and Sonzogni (1993) reported that the risk of shoulder injury was high when performing muscle exercise in the "high five" position, which means that external rotation occurs simultaneously as the shoulder is being abducted. In relation to this report, the lockout position in the weight-lifting snatch motion is similar to the high-five motion, and the shoulder adduction and internal rotation moments are also large, which would increase the possibility of injury. Moreover, repeated execution of the lockout position is strongly linked to injuries. Thus, setting the proper amount of training for the lock out motion should also be taken into consideration. With respect to elbow moments in P4, Fleisig (1995) reported an injury threshold of 64~120 Nm for elbow adduction moment. In this study, S2 athletes showed the highest value of 177% (99 Nm) on the right side during ST, which exceeded the injury threshold level by a lot. This can be attributed to the fact that with respect to the causes of elbow injuries among weight lifters, excessive expression of adductor muscles may easily appear from trying to control hyper-external rotation motion. As this motion is consistent with the motion that caused elbow injuries in Korean national team weight lifters during the 2012 London Olympics, it is an injury factor that needs much attention. Meanwhile, this value appeared at the ST level. Therefore, these athletes face higher risks of injuries in the adductor muscles that suppress elbow hyper-abduction than other injuries, which indicates the need for reinforcement training or motion modification training for stable lockout motion. With respect to elbow internal rotation moment, to control the barbell that moves backward during lockout, elbow abduction and external rotation motions are generated. Accordingly, elbow internal rotation moment is generated to stop overexertion and stabilize such motion, where S2 and S9 athletes showed an internal rotation moment of 328% (184 Nm) on the right side during ST and 203% (201 Nm) on the left side during MA, which exceeded the internal rotation threshold of 67 Nm suggested by Fleisig (1995).

CONCLUSION

The purpose of this study was to identify the injury-related motion types and possibility of injury in different body parts according to the progression of the snatch motion in weight lifting and thereby provide important information for developing injury prevention and modified training programs. The conclusions derived from the findings in this study were as follows: 1. Athletes with a history of knee injury, S3 and S10, showed low *B/R* ratio values in P3, presenting a high possibility of reinjury to the knees, such as ACL injury, from reduced ability of the biceps femoris to control the forward movement of the tibia relative to the femur when strong rectus femoris activity is expressed while the last pull motion is executed. Therefore, athletes with a history of knee injury or those who currently have a knee injury need to pay attention to the *B/R* ratio. 2. Injury-related motion and factors determined from moment analysis were as follows: A) In P2, when the weight of the barbell is withstood and lifted, the external moment in the knee joint to suppress the internal rotation motion exceeded the injury threshold level, suggesting the possibility of injury in the muscles that generate external rotation moment, which requires reinforcement training. B) An athlete showed ankle inversion moment, which is actively performed for powerful last pull motion 5 times higher than the injury threshold, which was assessed positively from an active muscle strength expression perspective. C) Large adduction and internal rotation moments are generated to prevent excessive knee abduction and external rotation immediately after lockout. Thus, the possibility of injury in the muscle group that generates adduction and internal rotation moments appeared high. D) In the lockout phase, the adduction moment for controlling hyperabduction of the elbow appeared higher than the injury threshold, even during ST, which represented the 60% level, which indicated a high possibility of injury to the elbow adductor muscle for all athletes. E) The lockout motion in weight lifting is similar to the "high five" position. As this motion generates large shoulder adduction and internal rotation moments, repeated training with this posture can increase the possibility of injury, which indicates the need to consider the amount of training for lockout when developing a training program.

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