Preface

The stability of the knee joint is crucial when playing most sport. Understanding the factors that increase the strength of the knee, especially the anterior cruciate ligament (ACL), is important to prevent knee injuries and improve treatment. Studying different sports, which place different demands on the knee joint, also helps us understand which exercises are most likely to strengthen the knee ligaments.

This study was commissioned by the Hong Kong Sports Development Board to investigate the effects of sports training on knee joint stability in athletes playing basketball, running and swimming. The knee joints of a group of students who didn't play sport regularly also were studied to see how they compared with the athletes' knees.

The results suggest that sports training may improve the strength of soft tissues in the knee joint. They also provide insights into the types of exercise that are most likely to strengthen the ACL. These results can be used by sports coaches and clinicians to help them design ligament-strengthening exercises for athletes and rehabilitation programmes for people with knee injuries.

Relationship of Kinetic Demands of Sports and Knee Joint Laxity

The study was carried out for SDB by:

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Abstract

The anterior laxity of the knee joint of dominant leg was measured in 64 adolescent athletes aged 14 to 20 in Hong Kong. Each subject was trained for at least two years at a minimum of 6 hours per week in their respective sports events, namely, basketball (n = 27), running (n = 20), swimming (n = 17). A group of age matched control subjects (n = 25) were also tested, who had not involved in any regular physical training. All measurements were performed by a physiotherapist with a KT-2000 knee arthrometer with 10 kgf of measuring force. The KT-2000 arthrometer captured the force and simultaneous displacement data of the knee joint. A computer program was written to calculate the total knee displacement (laxity) at 10 kgf of anterior drawer force, slope of the force/displacement data (stiffness) and rate of change in stiffness. Data were analysed with multivariate analysis of variance with $\alpha = 0.05$. Results revealed significant difference in the three variables measured. The total knee laxity increased in the order of swimmers < basketballers < runners < control, whereas the stiffness and rate of change in stiffness increased in the reverse order, i.e. control < runners < basketballers < swimmers. This result suggests that sports training could improve the strength of soft tissues in the knee joint, leading to a decrease in joint laxity. Furthermore, the difference in nature of sports could affect the biomechanical response of the soft tissues. Despite the low impact loading to the joint in swimming, the kinetic demand of this sport places the soft tissues of the knee joint under high tension, thus the swimmers presented with least laxity among the four groups. This finding has the clinical implication that exercise training could strengthen the soft tissues of the knee joint. It provides insights to coaches or clinicians to review their exercise programs when training athletes or in patient rehabilitation of knee joint injury cases.

Project details

<u>Objectives</u>

The sagittal stability of the knee joint is largely dependent on the integrity of the anterior cruciate ligament (ACL) (Butler et al 1980). Injury to the ACL will render the knee joint very unstable or early degenerative changes of the articular cartilages (Noesberger 1992, Daniel 1993). Rehabilitation for patients with ACL injury usually takes a long time and some of them may not be able to return to their pre-injury level of sports performance. It is therefore important to determine the factors that enhance the structural strength of this ligament in order to prevent injury or improve the result of rehabilitation should injuries occur.

Studies with animals have demonstrated exercises improved the structural strength of ligamentous tissues and its ultrastructural collagenous diameter profile (Oakes et al 1982). Similar studies in human have not been reported. However, there is evidence in the literature to suggest that immediately after endurance running, compliance of the knee joint ligaments increased, in which the knee joint became more lax in the sagittal plane (Sailor et al 1995). This has been attributed to the transient lengthening of the ACL due to viscoelastic “creep” behaviour (Woo et al 1990). Hitherto, the long-term effects of endurance running has not been well documented.

In light of this, the principal investigator (PI) conducted a study in Australia to compare the knee joint laxity in long term endurance runners with sedentary subjects. It was found that runners had significantly less anterior laxity than their sedentary counterparts at 30^{o} of knee flexion and the same trend was shown at 90^{o} knee flexion even though the difference was not statistically significant at that knee angle (Ng et al 1996, Wishart et al 1997). When the non-weight bearing joint laxity was taken as a variable, it did not affect the results, which suggested the difference was due to the effect of running. This may be due to the frequent loading of ACL in runners, which had strengthened the ligament and rendered it to provide better restraint to the knee.

Considering the kinetic demands of running, it is mostly repetitive extra-weight-bearing in nature. It would have been useful to determine if the amount of loading of an exercise could affect the total knee laxity. Furthermore, in that study, only the total laxity of the knee joint was measured but the stiffness was not known. In actual daily activities, knowing the structural stiffness of ACL is important because it determines how compliant the knee joint would be at submaximal loading forces which happen in most daily activities.

Therefore, the present study aimed at comparing the total anterior laxity and structural stiffness of the knee joint in athletes engaged in different sports, namely basketball (high impact loading and cutting activity); endurance running (high impact loading activity); swimming (non-weight-bearing but good muscle loading to the joint) and sedentary subjects (control). If significant difference was found among these groups, it would contribute to the understanding of the relationship between kinetic demands of exercise and the functional strength and stiffness of ACL. This will be very important in designing rehabilitation exercises for patients with ACL injury. More importantly, athletic training may also be modified by incorporating the exercise that leads to a stronger ACL so as to prevent injury from happening in athletes.

Methodology

Subjects:
A total of 64 athletes engaged in one of the above sports and 25 age matched secondary school students were recruited on voluntary basis from the Hong Kong Sports Institute and sports teams of local secondary schools. The athletes comprised of 27 in basketball, 20 in running and 17 in swimming.

The inclusion criteria were:
- Males and females aged between 14 and 20 years.
  Athletes engaged in any of the above sports for more than two years.
- Regular training for at least six hours per week.
- For control subjects, they must not be engaged in regular physical training.
- No previous knee injuries which required medical treatment for more than two weeks.

Based on the previous findings of the PI, it was estimated that 30 subjects in each group would be needed in order to have a statistical power of 0.8 for this study.

Testing procedures:
Each subject had to attend one testing session. All tests were conducted by a registered physiotherapist, in order to control for the inter-tester variability. Subjects must not engage in any strenuous physical activity for at least six hours prior to testing so as to control the immediate effect of exercise on joint laxity. All subjects were tested in supine lying position with the knee joint of the dominant leg flexed at 30^o. Dominant leg was determined as the one that the subject used to kick a ball.

A KT-2000 knee ligament arthrometer was used to measure the sagittal knee laxity of each subject. The KT-2000 arthrometer was applied to the lower leg of the subject according to the description of the users' manual. The operator applied a cyclic anterior/posterior force of 67 N through the KT-2000 handle so as to relax and acquaint the subject with the test. After setting the reference position, the cyclic anterior/posterior force was applied for another few times until the KT-2000 arthrometer output consistently registered 0 +/-0.5 mm with no force applied.

The measurement was taken with a 67 N of posterior push followed by 134 N of anterior draw (Wishart et al 1997). Analogue data of the KT-2000 measurements were output to an AT-Codas (DataQ Instruments, Akron) at 200 Hz, which performed filtering and digitization of the KT-2000 data for analysis.

Data analyses:
Data from the KT-2000 were stored in a personal computer for analysis. A correction factor was applied to each subject to eliminate the weight of the lower leg segment (Appendix 1). The weight-corrected data were then analysed at the point of 100 N of anterior drawer force according to the method of Maitland et al (1995). Three parameters were obtained with the analysis, namely, total sagittal displacement (laxity), change of displacement (stiffness), and rate of change of stiffness.

Statistical analysis of the data was performed using multivariate analysis of covariance with a SPSS 9.0 computer program. The covariates were gender, body weight and height. Results revealed that none of the covariates was significant with $p = 0.757$, 0.902 and 0.823, respectively. Therefore, the data were analysed with multivariate analysis of variance. The level of significance was set at 5% and significant results were further analysed with Post-hoc contrasts to identify the data pairs that were significantly different.

Results

Table 1 shows the means, standard deviations (in brackets), and p values of each parameter tested for the four groups. The raw data of all the measurements are shown in Appendix 2.

	Basketball	Running	Swimming	Control	p value
Laxity (mm)	6.349 (2.292)	7.330 (2.078)	5.961 (2.303)	7.789 (2.404)	0.035
Stiffness (N/mm)	47.542 (23.088)	45.206 (23.089)	57.769 (32.368)	37.856 (15.903)	0.067
Change of stiffness (N^2/mm)	25.742 (33.669)	18.226 (27.084)	33.086 (43.260)	4.685 (26.811)	0.034

Post-hoc contrasts reveal none of the sports groups were significantly different in any of the parameters tested. For the laxity and stiffness measurements, subjects in swimming and basketball groups were significantly different from the control. For the change of stiffness measurements, the swimming group was significantly different from the control.

Discussion

This study shows that long term sports training affected the compliance of the knee joint, such that there was a decrease in sagittal laxity and an increase in stiffness during passive drawing manoeuvre. The mean values revealed a general trend of difference in tissue compliance with different sports events, despite the results were not statistically significant.

The present finding of no significant difference between the running group and control group was unexpected and different from the previous findings of the Ng et al (1996), in which the runners were found to have significantly less laxity than the control subjects. Comparing the mean values of the two studies, it can be seen that the present study (7.330 mm for runners and 7.789 mm for control) had higher laxity values than that of the previous study (5.225 for runners and 6.394 mm for control). An explanation for the higher laxity in the control group of the present study could be due to the fact that we recorded total laxity of -67 N to +100 N of drawer force, whereas in the previous study, the laxity was measured with only +134 N of drawer force. For the runners, our laxity value is substantially lower than that of the previous study. We suspect this could be due to the difference in level of exercise between the two groups of runners. We recruited subjects with at least two years of training in running. Most of our subjects were trained between 2 to 4 years. For the previous study, the training intensity was decidedly higher than the present study, because most of the subjects had more than five years of training at the level of running > 20 km per week. The relatively low training intensity of our present subjects could also explain the insignificant difference between the runners and control subjects.

Considering the other two sports groups, they had significantly lower laxity and higher stiffness than the control, which substantiated our hypothesis. The reason for testing stiffness and change of stiffness was that these parameters had been shown by Maitland et al (1995) to have higher sensitivity than knee laxity in assessing subjects with ligamentous injuries. Furthermore, stiffness is a functional parameter, which signifies the biomechanical response of the knee joint to loading.

From the point of mechanical consideration, the kinetic demands of basketball would impose very high loading to the joint structures, whereas loading to the joint in swimming would be relatively low. However, forces caused by contraction of muscles that cross the knee are more important than the joint compression in soft tissue loading, as the forces in the former case requires the restraining action of the soft tissues to maintain joint integrity. When considering the swimming action, it is an open kinetic chain activity, in which the shear loading to the joint is very high, which puts direct tensile loading to the soft tissues that provide the restraining forces. Therefore, this group of subjects presented the least laxity and highest stiffness in the present test.

The stiffness in the soft tissues is important for injury prevention and functional restraint to excessive movements of the joint. The present finding provides insight to coaches and clinicians in their training for athletes and patients in order to improve knee joint stability.

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Appendix 1

Kinanthropometric adjustments for KT-2000 measurements

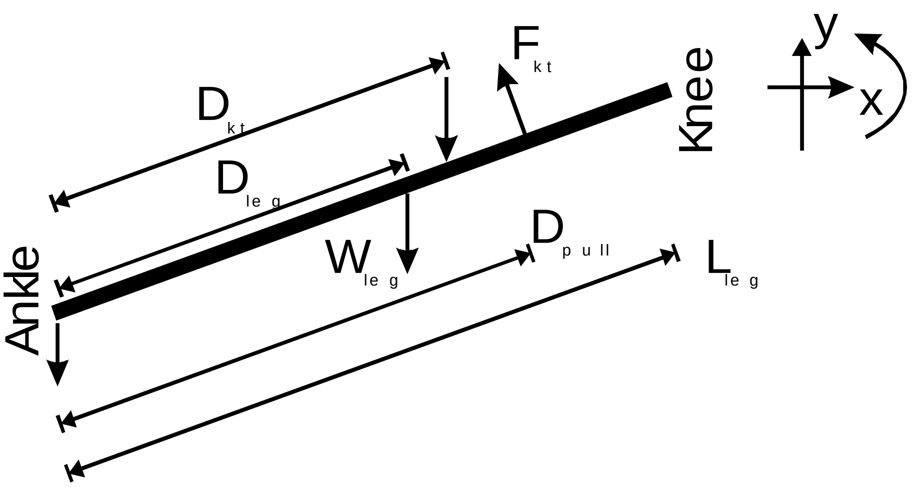
Segment weight and center of gravity from:
Chandler 1975 in Enoka R. *Neuromechanical Basis of Kinesiology* (Second Ed)
Champaign: Human Kinetics 1994; 44-48

W_{body}=subject's body weight in Newtons
Shank weight (W_{leg}) = 0.044BW -1.75 N
F_{kt}=Measured force at KT in Newtons
Length of tibia =L_{leg}
distance of center of gravity of the leg from the tibiofemoral joint = 0.41*L_{leg}
Center of gravity of leg from ankle =D_{leg}
D_{leg}= L_{leg} - 0.41*L_{leg}

M_{pull}=Moment due to pull on KT
M_{leg}=Moment due to the weight of the leg
M_{kt}=Moment due to KT
M_{ankle}=Moment calculated at ankle joint

=angle of leg from horizontal (estimated to be 20^o)

Weight due to kt instrumentation (2 kg) W_{kt}=20 N
D_{kt}=measured distance of center of gravity of kt from the ankle joint.= L_{leg}-0.16 m
D_{pull}=distance of pull force application from ankle joint= L_{leg}-0.10 m



Definitions for Kinantropometric Normalization

Positive forces are in upward and right-hand directions. Positive moments are in the counter-clockwise direction.

If the force due to gravity on the mass of the leg is balance by the force applied at the KT, then:

$M_{ankle}=M_{pull}+M_{kt}+M_{leg}=0$

$M_{pull}=F_{pull}*D_{pull}$
$M_{kt}=W_{kt}*D_{kt}$
$M_{leg}=W_{leg}*D_{leg}$

$(F_{pull} * D_{pull}) + (W_{kt}*D_{kt})+(W_{leg}*D_{Leg})=0$

$F_{pull}*D_{pull}=-(W_{kt}*D_{kt})-(W_{leg}*D_{leg})$

$F_{pull}= -(W_{kt}*D_{kt})-(W_{leg}*D_{leg})/D_{pull}$

$F_{pull} =$

$$\frac{-[(\text{Cos}\quad)(-20N)]*(L_{leg}-0.16\ m)]+[(\text{Cos}\quad)(0.044*BW-1.75N)*(L_{leg}-0.41*L_{leg})]}{(L_{leg}-0.10\ m)}$$

$F_{pull}=$

$$\frac{+18.7939\ (-0.16 + L_{leg}) +0.554419\ L_{leg}\ (-1.75 + 0.044\ BW)}{-0.1 + L_{leg}}$$

For a leg length of 0.40m and a body weight of 636 N the correction factor would be: -36.1 N

Appendix 2

Raw data for subjects. Item 1 = Basketball, 2 = running, 3 = swimming, 4 = control, displ = total laxity, slope = stiffness, accel = rate of change of stiffness.

SUBJECT	ITEM	DISPL	SLOPE	ACCEL	SEX	WEIGHT	HEIGHT
1.00	1.00	3.79	78.88	47.87	2.00	51.00	160.00
2.00	1.00	5.66	38.09	15.22	2.00	49.00	165.00
3.00	1.00	5.46	38.76	12.68	2.00	47.00	161.00
4.00	1.00	5.91	79.46	54.39	1.00	67.00	186.00
5.00	1.00	4.71	41.78	13.98	2.00	51.00	169.00
6.00	1.00	5.33	57.08	20.83	1.00	60.00	160.00
7.00	1.00	6.58	36.69	9.67	2.00	52.00	164.00
8.00	1.00	7.84	47.07	14.52	1.00	72.00	177.00
9.00	1.00	7.37	25.97	8.45	2.00	62.00	179.00
10.00	1.00	5.03	59.13	18.72	1.00	68.00	179.00
11.00	1.00	5.18	80.96	106.36	1.00	77.00	186.00
12.00	1.00	13.39	9.18	2.53	1.00	72.00	179.00
13.00	1.00	5.87	34.05	11.62	2.00	43.00	160.00
14.00	1.00	8.70	52.12	16.80	1.00	63.50	176.00
15.00	1.00	2.89	101.63	153.66	1.00	77.00	184.00
16.00	1.00	4.16	50.44	21.80	1.00	68.00	168.00
17.00	1.00	9.45	13.94	.68	1.00	54.00	172.00
18.00	1.00	9.02	31.07	1.71	1.00	61.50	177.50
19.00	1.00	3.04	39.38	7.83	2.00	61.00	173.00
20.00	1.00	7.87	26.27	5.80	1.00	71.00	181.00
21.00	1.00	5.11	75.54	28.77	1.00	67.00	183.00
22.00	1.00	8.05	15.11	2.45	2.00	40.00	162.00
23.00	1.00	4.75	37.19	25.36	1.00	60.00	178.00
24.00	1.00	4.31	77.86	38.10	1.00	74.00	178.00
25.00	1.00	6.07	50.54	14.70	1.00	70.00	181.00
26.00	1.00	8.01	54.72	35.76	1.00	64.00	172.00
27.00	1.00	7.88	30.73	4.77	1.00	63.00	175.00
28.00	2.00	7.42	54.95	22.26	1.00	80.00	175.00
29.00	2.00	6.05	17.74	9.39	1.00	61.00	177.00
30.00	2.00	8.40	24.65	7.85	1.00	55.00	170.00
31.00	2.00	8.87	14.33	1.80	2.00	49.00	157.00
32.00	2.00	11.14	15.70	3.27	2.00	45.00	158.00
33.00	2.00	6.04	67.44	27.99	2.00	39.00	159.00
34.00	2.00	7.58	77.14	59.42	1.00	57.00	172.00
35.00	2.00	6.75	37.27	9.22	1.00	62.00	170.00
36.00	2.00	4.48	79.50	47.77	1.00	57.00	166.00
37.00	2.00	5.53	48.81	11.12	1.00	60.00	175.00
38.00	2.00	7.64	65.05	53.63	1.00	59.00	170.00
39.00	2.00	3.65	63.51	25.72	1.00	50.00	165.00
40.00	3.00	5.83	36.17	14.45	1.00	70.00	180.00
41.00	3.00	2.20	97.94	60.04	1.00	55.00	165.00
42.00	3.00	9.21	20.09	3.72	1.00	61.00	172.00
43.00	3.00	4.17	36.18	15.08	1.00	50.00	165.00

SUBJECT	ITEM	DISPL	SLOPE	ACCEL	SEX	WEIGHT	HEIGHT
44.00	3.00	6.07	94.30	62.89	1.00	62.00	174.00
45.00	3.00	1.48	140.48	138.00	1.00	60.00	170.00
46.00	4.00	6.60	31.82	-18.58	2.00	43.00	154.00
47.00	4.00	3.14	60.28	-33.69	2.00	52.00	164.00
48.00	4.00	12.16	27.31	7.65	1.00	63.00	175.00
49.00	4.00	7.69	26.35	3.30	1.00	43.00	156.00
50.00	4.00	10.07	17.75	-5.60	2.00	48.00	161.00
51.00	4.00	5.29	64.32	43.02	1.00	65.00	174.00
52.00	4.00	7.81	57.04	18.97	2.00	45.00	161.00
53.00	4.00	12.54	18.02	12.11	2.00	53.00	154.00
54.00	4.00	6.65	22.47	-27.24	2.00	50.00	159.00
55.00	4.00	5.21	39.55	-28.81	2.00	44.00	152.00
56.00	4.00	7.56	31.24	-7.75	2.00	66.00	166.00
57.00	4.00	4.85	32.78	-.02	1.00	54.00	173.00
58.00	4.00	6.26	27.23	-46.88	1.00	58.00	163.00
59.00	4.00	7.10	45.92	40.60	2.00	41.00	164.00
60.00	4.00	9.84	29.04	2.33	2.00	52.00	153.00
61.00	4.00	11.91	37.37	22.28	1.00	82.00	180.00
62.00	4.00	5.34	26.21	-16.30	2.00	58.00	158.00
63.00	4.00	8.93	64.87	66.55	1.00	55.00	172.00
64.00	4.00	6.26	37.47	11.83	2.00	51.00	162.00
65.00	4.00	7.98	38.90	7.65	2.00	45.00	165.00
66.00	4.00	8.17	16.88	4.33	2.00	48.00	165.00
67.00	4.00	8.86	70.82	53.02	1.00	60.00	173.00
68.00	4.00	7.07	35.35	10.89	1.00	56.00	170.00
69.00	4.00	6.64	57.63	-5.57	2.00	54.00	163.00
70.00	4.00	10.81	29.79	3.04	2.00	50.00	165.00
71.00	2.00	9.66	34.94	26.06	2.00	48.00	163.00
72.00	2.00	5.66	48.17	-23.02	1.00	55.00	178.00
73.00	2.00	7.94	39.33	15.26	1.00	63.00	175.00
74.00	2.00	11.58	31.91	7.78	1.00	56.00	163.00
75.00	2.00	9.16	92.53	86.57	2.00	42.00	156.00
76.00	2.00	7.07	15.92	-15.04	1.00	58.00	168.00
77.00	2.00	5.08	37.74	5.51	1.00	63.00	175.00
78.00	2.00	6.90	37.48	-18.04	1.00	58.00	169.00
79.00	3.00	6.65	39.07	30.18	1.00	82.00	182.00
80.00	3.00	4.39	53.41	-.40	1.00	63.00	175.00
81.00	3.00	5.42	24.62	10.84	1.00	67.00	173.00
82.00	3.00	4.82	76.03	3.71	1.00	61.00	173.00
83.00	3.00	8.88	60.25	38.64	1.00	63.00	175.00
84.00	3.00	7.12	19.49	7.60	1.00	68.00	170.00
85.00	3.00	9.35	55.42	36.07	1.00	70.00	185.00
86.00	3.00	7.22	37.45	.58	1.00	68.00	172.00
87.00	3.00	4.58	86.89	131.65	1.00	66.00	172.00
88.00	3.00	5.32	55.23	-5.97	1.00	59.00	168.00
89.00	3.00	8.62	49.06	15.38	1.00	65.00	180.00