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Do Age, Gender and BMI Affect Contralateral Uninjured Knee Joint Laxity Characteristics in Anterior Cruciate Ligament Reconstruction Patients?

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Abstract: Purpose of research: Our study purported to prove the effects of age, gender and Body Mass Index (BMI) on contralateral uninjured knee laxity in the Anterior Cruciate Ligament (ACL) injured population. Previous literature on effects of age, gender and BMI on healthy knee laxity do not prove a consistent association of these factors. This study aims to find the reference values for contralateral uninjured knee laxity of different groups of age, gender and BMI in the ACL injured Australian population. Principal results: This retrospective cohort study analysed 645 patients who underwent primary ACLR between May 2016 and November 2023 with GNRB arthrometer assessment of the uninjured knee at 12 months post-operatively. Anterior tibial translation was measured at 134 N, 150 N, and 200 N. Welch's *t*-tests, one-way ANOVA, and linear regression were used to examine the effects of age, sex, and BMI on uninjured knee laxity. Uninjured knee laxity did not differ significantly between paediatric and adult patients, between sexes, or across BMI categories. There was no association between age, gender, BMI and uninjured knee laxity on linear regression analysis. Reference values for contralateral uninjured knee laxity across age, sex, and BMI subgroups in the ACL injured Australian population were established. Major conclusions: Uninjured knee joint laxity characteristics did not differ significantly between paediatric and adult cohorts, between sexes, or across BMI categories in the ACL injured population. The prognostic value of knee laxity on ACL injury risk is yet to be established. Reference values for contralateral uninjured knee laxity in the ACL injured Australian population were derived.

Keywords: anterior cruciate ligament; knee laxity; anterior tibial translation; anterior cruciate ligament injury; anterior cruciate ligament reconstruction; GNRB

1. Introduction

The factors predisposing an individual to anterior cruciate ligament (ACL) injury is inherently multifactorial, reflecting a complex interaction of intrinsic and extrinsic risk factors that vary across individuals and populations. Differences in knee laxity characteristics due to age, gender and Body Mass Index (BMI) may play a role in the risk of sustaining ACL injuries. Increased inherent healthy joint laxity is a hypothesized risk factor and there exist various scoring systems used to stratify a patient's level of joint laxity. A clinical examination accumulating scores based on joint mobility is the standard method for evaluating generalised joint hypermobility (GJH), called the Beighton Score, which is a modification of the Carter and Wilkinson scoring system developed in 1964 [1,2]. The

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adjusted scores of the Bulbena criteria have also correlated highly with the Beighton Score. Carter and Wilkinson's score, however, is less commonly used [3].

There were several studies conducted to ascertain the interplay of age, gender and healthy knee laxity. Quatman et al. examined knee laxity in pre-pubertal, pubertal and post-pubertal male and female athletes using the Beighton Score and found that pre-pubertal male and females showed similar rates of hypermobility [4]. However, during pubertal and post-pubertal stages, female athletes had a significantly higher prevalence of hypermobility [4]. Their study relied on physiological hyperextension as a surrogate marker of knee joint laxity, but did not record tibial translation in the sagittal plane [4]. Tagesson et al. conducted a controlled laboratory study which found that during childhood (8–13 years), boys had greater knee laxity than girls, however upon reaching adulthood (18–30 years), women had greater knee laxity than men [5]. These findings suggest that hormonal and mechanical changes during puberty may result in increased knee laxity in post-pubertal women. The current literature regarding GJH and risk of ACL rupture is conflicting. A systematic review previously found that GJH is associated with an increased risk of ACL injury in male patients with majority of the primary articles classifying GJH based on the Beighton Score [6]. For female patients, they found that GJH was associated with increased risk of ACL tears [6]. Paradoxically, a lower Beighton score indicating lower levels of laxity was associated with an increased risk of ACL injury [6]. Despite the Beighton Score being the standard for measuring GJH, its use in the context of lower limb injury remains controversial due to the scoring system predominantly relying on joints of the upper limb, preventing a true assessment of laxity of the knee joint itself [1,2]. In another study, Vaishya and Hasija found that patients with ACL ruptures and female patients were more likely to have GJH [7]. Among the anatomical factors that increase anterior tibial translation (ATT) and ACL loading independent of age, sex and BMI are the increased lateral posterior tibial slope, intercondylar notch stenosis and a shallower medial tibial plateau [8,9].

There are several validated tools to objectively measure the knee joint laxity in terms of anterior sagittal translation which have been found to have good sensitivity. The GRNB (GENOUROB) arthrometer is one such validated tool to diagnose complete and partial ACL tears [10–14]. Several studies have found that the GNRB arthrometer has a superior intra-examiner and inter-examiner reproducibility, was less operator dependent, and the results were less side-dependent in healthy knees when compared to the KT-1000 knee ligament arthrometer at 134 N [10,12,15]. Bouguennac et al. compared the GNRB arthrometer with the TELOS device and found that the GNRB arthrometer offers greater reproducibility [16]. Additional benefits of the GNRB arthrometer in comparison with the TELOS device are that it requires no radiation and allows for the use of greater applied forces [16]. Lefevre et al. investigated the diagnostic value of the GNRB arthrometer in comparison with the TELOS device in patients with partial ACL tears as confirmed by clinical examination, MRI findings and knee laxity measurements and found that the GNRB arthrometer had superior diagnostic value compared to the TELOS device at 250 N [13].

In our study, we have only included ACL injured population with a unilateral ACL injury and contralateral uninjured knee. In previous studies, it has been proven that the altered biomechanics in the ACL injured population causes an anterior tibial position and increased internal tibial rotation not only in the injured knee but also in the uninjured knee at 2 years post injury [17]. Rotational laxity is also found to be higher in the ACL injured population compared to the uninjured population with females possessing increased internal and external tibial rotation compared to males [18].

This study aims to address three key objectives: To find out if paediatric ACL injury patients have higher uninjured knee laxity values as compared to adults, if females have higher uninjured knee laxity values compared to males, and to investigate the association of uninjured knee laxity and BMI in the ACL injured population. Through our study, we will help establish the reference values for contralateral uninjured knee laxity in the ACL injured population for different groups of age, gender and BMI in Australia, which we believe, has not been previously reported.

2. Methods

2.1. Study Design and Setting

This was a retrospective observational study of all ACL injured patients who were surgically treated with an ACLR by five fellowship-trained orthopaedic knee surgeons at a single orthopaedic research centre in Sydney, Australia. Informed consent was obtained and the rights of subjects were protected. Post-operative measurements of both knees with the GNRB arthrometer are routinely performed at this centre for ACLR patients. Patients who underwent an ACLR, participated in the 12-month post-operative follow-up and had the uninjured knee tested with the GNRB arthrometer between May 2016 and November 2023 were included in this study. The uninjured knee

was examined clinically on presentation and follow up to ascertain the ligament integrity and if found to have absence of history and signs of clinical injury, was considered for inclusion in this study. No imaging was performed on the contralateral uninjured knee during the period of study. In our study, the consideration of anatomical factors like increased posterior tibial slope, joint congruency and intercondylar notch stenosis has not been evaluated as a factor for analysis.

The exclusion criteria were patients who had developed contralateral ACL injuries on the previously uninjured knee before the 12-month GNRB arthrometer assessment and patients who had a prior ACLR on their contralateral "uninjured" knee. For patients who had a revision ACLR on the same knee after 12-months, only the index surgery was considered.

2.2. Measurements

Knee laxity was measured by trained research assistants according to the GNRB protocol devised by the manufacturer GENOUROB [10]. The patients were in supine position with the knee at 20 degrees of flexion which is then fixed to the machine with two straps: one at the ankle and one at the knee. A sensor is placed on the tibial tuberosity to measure the anterior tibial displacement, and a jack is simultaneously positioned on the upper posterior segment of the calf which applies a calibrated posterior-to-anterior force mimicking Lachman's test. The anterior tibial displacement (measured in millimetres) was measured when the jack applied forces at 134 N, 150 N and 200 N sequentially [1]. If the patient experienced pain during the test while assessing laxity at any of the three force levels, then the test was stopped. Three anterior tibial displacement measurements were taken at each force applied and the mean of these values were imputed into the SOCRATES Orthopaedic Outcomes Software database (Ortholink Pty Ltd., Sydney, NSW, Australia). Factors such as time since last physical activity or warmup prior to measurement were not accounted for in our study while carrying out the measurements.

2.3. Statistical Analysis

Descriptive statistics were used to describe baseline characteristics of our patients. Normal distribution for each group was confirmed. Welch's *t*-test was used for comparison between paediatric (age ≤ 16 years) and adult (age 17 years and above) groups and between genders for our primary and secondary outcome. One way ANOVA with Welch's approximation was used to compare mean translation between our different age and BMI subgroups. To evaluate the potential for missing-data bias, patients with and without BMI were compared on age, sex distribution, and anterior tibial translation. Welch's *t*-tests were used for continuous variables and a chi-square test for sex. A multiple linear regression model was performed to analyse the association of ATT, with age and BMI as covariates and gender as the grouping variable. A p-value < 0.05 was considered statistically significant. All statistical analyses were performed using jamovi 2.6.45.0.

3. Results

3.1. Sample Population Characteristics

763 patients were initially chosen to be a part of this study and were then subjected to the inclusion and exclusion criteria to decide their eligibility to participate in the study. 15% (118 of 763) of patients were excluded as per the exclusion criteria outlined above. 8% of (61 of 763) patients were excluded as they had revision ACL reconstructions. In case of revision ACL reconstruction patients, only the primary (index) surgery was values were considered for analysis while the values collected after revision ACLR were excluded from analysis. 6.3% (48 of 763) patients were excluded as they had developed injuries to the contralateral healthy knee within the 12-month post-operative period. 1.2% (9 out of 763) patients had presented with bilateral ACL injuries and were thus excluded. A total of 645 patients were eligible for analysis in this study as shown in Figure 1.



Figure 1. Patient selection flow diagram showing the derivation of the study population.

3.2. Patient Population

The cohort comprised of 115 (18%) paediatric patients, 326 (51%) patients aged 17 to 30 years, 155 (24%) aged between 31 to 45 years and 49 (8%) patients older than 45 years. The youngest patient was 9 years of age, and the oldest patient was 64 years of age. There were 288 female patients (45%) and 357 (55%) male patients enrolled in this study.

3.3. Effect of Age on Uninjured Knee Laxity in the ACL Injured Population

In the table below (Table 1), the mean and standard deviation values were very similar with no major differences noted between age groups. The normative values for contralateral uninjured knee laxity for the ACL injured population in each age group from the patients recruited in this study has been outlined in Table 1 at 134 N, 150 N and 200 N. One way ANOVA with Welch's assumption showed that there was no significant association of age with uninjured knee laxity at 134 N ($p = 0.565$), 150 N ($p = 0.294$) and 200 N ($p = 0.456$). Thus, there was no association between age and contralateral uninjured knee laxity in the ACL injured population.

Table 1. Reference values of Contralateral uninjured-Knee Laxity by Age Groups. Abbreviations: N (number of patients), SD (standard deviation). Tibial translation values are reported in millimetres.

Force Applied	Group (Years)	N	Mean	SD	Minimum	Maximum	Mean Difference	95% Confidence Interval	
								Lower	Upper
134 N	0–16	115	5.25	1.77	2.08	12.70	-	4.93	5.58
	17–30	326	5.05	1.76	0.70	13.10	0.201	4.86	5.24
	31–45	155	5.10	1.84	1.30	11.20	0.153	4.80	5.40
	>45	49	5.40	2.08	2.10	10.00	−0.14	4.83	5.95
150 N	0–16	115	5.96	1.78	2.78	13.60	-	5.63	6.28
	17–30	325	5.67	1.75	1.20	14.00	0.290	5.48	5.86
	31–45	155	5.74	1.92	2.11	12.70	0.208	5.44	6.06
	>45	49	6.13	2.17	2.50	10.70	−0.13	5.51	6.67
200 N	0–16	114	7.62	1.78	3.90	12.80	-	7.29	7.95
	17–30	324	7.41	1.90	2.00	16.20	0.218	7.20	7.61
	31–45	152	7.39	1.98	3.30	12.40	0.228	7.07	7.72
	>45	49	7.86	2.50	3.60	14.40	−0.19	7.15	8.49

3.4. Do Children Have More Laxity in Their Uninjured Knees When Compared to Adults?

The study group was divided into two groups: patients aged 16 years and below were considered as the paediatric population, and those 17 years and above of age were considered as the adult population. Welch's *t*-test was performed to see if there was a relationship in the uninjured knee laxity values between the paediatric and adult groups (Table 2). There were no statistically significant differences between the paediatric and adult groups at 134 N ($p = 0.410$), 150 N ($p = 0.236$) and 200 N ($p = 0.374$). Thus, paediatric ACL injured population did not possess higher contralateral uninjured knee laxity compared to adult ACL injured population.

Table 2. Reference values of Contralateral Uninjured-Knee Laxity in Paediatric and Adult Patients in the ACL injured Australian population. Abbreviations: N (number of patients), SD (standard deviation). Tibial translation values are reported in millimetres.

Force Applied	Group	N	Mean	SD	Minimum	Maximum	Mean Difference	95% Confidence Interval	
								Lower	Upper
134 N	Paediatric	115	5.25	1.77	2.08	12.70	0.153	4.93	5.58
	Adult	530	5.10	1.82	0.70	13.10	-	4.95	5.26
150 N	Paediatric	115	5.96	1.78	2.78	13.60	0.224	5.63	6.28
	Adult	529	5.73	1.85	1.20	14.00	-	5.57	5.89
200 N	Paediatric	114	7.62	1.78	3.90	12.80	0.179	7.29	7.95
	Adult	525	7.44	1.99	2.00	16.20	-	7.27	7.62

3.5. Effect of Gender on Uninjured Knee Laxity

Table 3 enumerates the reference values for the uninjured knee laxity for males and females taken at 134 N, 150 N and 200 N. Welch's *t*-test found no differences of uninjured knee laxity between genders at 134 N ($p =$

0.303), 150 N ($p = 0.187$) and at 200 N ($p = 0.080$). A further subgroup analysis between paediatric male, paediatric female, adult male and adult females using one-way ANOVA found no association with the uninjured knee laxity at 134 N ($p = 0.284$), 150 N ($p = 0.141$) and 200 N ($p = 0.145$). Thus, we found no association between gender and contralateral uninjured knee laxity in the ACL injured population.

Table 3. Reference values of Contralateral uninjured-Knee Laxity for both genders in the ACL injured Australian population. Abbreviations: N (number of patients), SD (standard deviation). Tibial translation values are reported in millimetres.

Force Applied	Group	N	Mean	SD	Minimum	Maximum	Mean Difference	95% Confidence Interval	
								Lower	Upper
134 N	Female	288	5.21	1.82	1.61	13.10	-	5.00	5.42
	Male	357	5.06	1.80	0.70	12.70	−0.15	4.87	5.25
150 N	Female	287	5.88	1.90	2.11	14.00	-	5.66	6.10
	Male	357	5.69	1.78	1.20	13.60	−0.20	5.50	5.87
200 N	Female	284	7.63	2.04	3.30	16.20	-	7.39	7.87
	Male	355	7.36	1.87	2.00	13.40	−0.27	7.16	7.55

3.6. Effect of BMI on Uninjured Knee Laxity

BMI data was obtained for 497 (77% of total cohort of 645) patients which was categorised into four categories: Underweight (<18.5), Normal weight (18.5–25), Overweight (25–30) and Obese (>30). The number of patients in the underweight and obese category were small and since only 77% of the BMI data was available for analysis, the results should be interpreted with caution. In Table 4, the reference values for the uninjured knee laxity for all the BMI groups are given with consistent values across all four BMI categories at each force level. However, the obese group demonstrates marginally lower mean values compared to the normal weight group at all three force levels. The degree of variation was minimal and standard deviations overlapped across groups, indicating no clinically meaningful differences in the uninjured knee laxity between BMI categories. One-way ANOVA with Welch's assumption revealed that there was no statistical association of BMI on contralateral uninjured knee laxity at 134 N ($p = 0.202$), 150 N ($p = 0.209$) and at 200 N ($p = 0.234$) in the ACL injured Australian population, according to the analysis on our cohorts.

Table 4. Reference values of Contralateral uninjured-Knee Laxity of all BMI Groups in the ACL injured Australian population. Abbreviations: N (number of patients), SD (standard deviation). Tibial translation values are reported in millimetres.

Force Applied	Group	N	Mean	SD	Minimum	Maximum	Mean Difference	95% Confidence Interval	
								Lower	Upper
134 N	Underweight	9	4.88	0.99	3.60	7.00	-	4.12	5.64
	Normal weight	299	5.28	1.88	1.80	12.70	0.399	5.06	5.49
	Overweight	154	5.02	1.88	1.60	13.10	0.147	4.73	5.32
	Obese	35	4.59	1.73	0.70	8.60	−0.29	3.99	5.18
150 N	Underweight	9	5.41	1.24	4.00	8.10	-	4.46	6.37
	Normal weight	299	5.91	1.89	2.40	13.60	0.494	5.69	6.12
	Overweight	154	5.72	1.89	2.60	14.00	0.310	5.42	6.02
	Obese	35	5.15	1.87	1.20	9.40	−0.26	4.51	5.79
200 N	Underweight	9	7.32	1.72	5.30	11.20	-	6.00	8.65
	Normal weight	295	7.62	1.95	3.60	14.40	0.295	7.39	7.84
	Overweight	153	7.50	2.07	3.90	16.20	0.174	7.17	7.83
	Obese	35	6.80	2.12	2.00	11.10	−0.52	6.08	7.53

3.7. Linear Regression Analysis

The analysis showed that there is no relationship of age, gender, and BMI to the uninjured knee laxity as the R^2 values at 134 N (0.00261), 150 N (0.00426) and 200 N (0.00622) were found to be weak predictors with no correlation of age, BMI and gender with contralateral uninjured knee laxity in the ACL injured population. There is a possibility of missing data bias since only 77% patients' BMI data was available for analysis.

Table 5. Multiple linear regression analysis results at 134 N, 150 N and 200 N to assess effect of age, gender and BMI on uninjured knee laxity values.

		β Values (Regression Coefficient)	95% Confidence Intervals		*p* Values	Sample Size	R^2 Values
			Lower	Upper			
134 N	Age	0.0268	−0.0507	0.1043	0.497	645	0.00261
	Gender	−0.0818	−0.2375	0.0739	0.303		
	BMI	−0.0156	−0.0931	0.0618	0.692		
150 N	Age	0.0371	−0.0403	0.1146	0.347	644	0.00426
	Gender	−0.1054	−0.2611	0.0503	0.184		
	BMI	−0.0121	−0.0896	0.0653	0.759		
200 N	Age	0.0341	−0.0436	0.1118	0.389	639	0.00622
	Gender	−0.1410	−0.2972	0.0152	0.077		
	BMI	0.0126	−0.0651	0.0903	0.750		

We compared the age and laxity values between the groups with and without BMI data using independent samples *t*-test to ascertain any effect of missing BMI data on our results. The effect of missing BMI data on gender was assessed using Chi square test. We found that there was no difference between the group with BMI data and the group without BMI data on age ($p = 0.344$), laxity values at 134 N ($p = 0.608$), 150 N ($p = 0.613$), 200 N ($p = 0.261$) and gender ($p = 0.338$) on further analysis.

Therefore, to conclude all our findings, there was no relationship found between age, gender, and BMI on contralateral uninjured knee laxity in the ACL injured population. Reference values for contralateral uninjured knee laxity in different age, gender and BMI groups in the ACL injured Australian population have thus been reported through our study.

4. Discussion

With an increasing incidence of ACL injuries, a better understanding of factors involved in ACL injuries should be explored. This study aimed to determine the effects of age, gender and BMI singularly, and in concert, on the contralateral uninjured knee laxity in the ACL injured Australian population. The reference values for the uninjured knee laxity in the ACL injured Australian population were also established.

In our study, we found that age does not have a statistically significant association to uninjured knee laxity characteristics and found no differences between tibial translation in the anteroposterior plane between our paediatric and adult groups. This contrasts with Tagesson et al. who found that children had greater sagittal tibial translation compared to their adult group [5]. It is important to note differences in methodology as our study classified patients as paediatric (aged ≤ 16) and adult (>17), whereas their study classified patients as children (8–13 years) and adults (18–30 years) [5]. Tagesson et al. found differences in knee-joint laxity at 90 N using their instrumented Lachman's test, which was not used for our study [5]. Our results are contradictory to the study done by Cojean et al. which states that children were more lax compared to adults when measured on GNRB [19]. However, the age groups in their study were different since they considered 8–13-year-olds as children and 14–17-year-olds as adults [19]. In addition, the measurements were made at 67 N, 89 N, 134 N, 150 N and 200 N, whereas in our study we only measured the laxity on the latter three powers [19]. Their patients were recruited due to presentation with an acute ACL injury on the contralateral leg, which was similar to our study but the GNRB measurements were done before the injured leg was operated [19]. In the study done by Cojean et al., the contralateral uninjured knee was assessed before the ACL injured knee was operated and thus may state the native knee laxity prior to adaptive changes in neuromuscular control which happens 1–2 years post injury [17,19]. The contrasting findings may be attributed to differences in age groups, methodology, and the force levels applied. Joint mobility is affected by aging due to the increase in collagen fibre diameters which make it more plastic to deformation. After collagen maturation, the tensile strength plateaus and then subsequently is found to decrease as age increases [20]. Amount of glycosaminoglycans and water volume by weight, decreases in the ligament substance as age increases, which leads to reduced critical fibre distance between the collagen fibres [20]. This causes abnormal cross links between the fibres and thus causes loss of extensibility [20]. This means that there should be a decrease in uninjured knee laxity values as the age and joint degeneration increases, however, as the uninjured knee laxity is hypothesised to also depend on activity levels of the patients, the predictability of the uninjured knee laxity is difficult.

When males were compared to females, there were no statistically significant differences in the uninjured knee joint laxity at 134 N, 150 N and 200 N. These results do not concur with the findings of Cojean et al., who found differences between the following groups: adolescent/children girls and adolescent/children boys. 8–13-year-olds

were considered as children and 14–17-year-olds were considered as adolescents. They found increased laxity in girls compared to boys at 67 N ($p = 0.007$), 89 N ($p = 0.006$), 134 N ($p = 0.005$), 150 N ($p = 0.021$) but no difference was noted at 200 N. However, their study was done on pathological knees, which differs from our study hence explaining the contrasting results [19]. A study done by Zyroul et al. showed that there was a trend of increased values of laxity noted in females in their healthy knees but failed to show any association of female gender to increased uninjured knee laxity on analysis with ANOVA which is similar to our study [20]. Inadequate protective ability of the quadriceps musculature in women may show increased ATT [21]. Higher knee laxity in female patients in these studies may also be related to differences in directions and magnitudes of forces applied through the knee joint with females having greater knee abduction at initial contact and less peak knee flexion during stance of change of direction tasks [22]. Several studies indicate that changes in the level of female sex hormones also affects ligament laxity by affecting the overall structure of the ligament and biomechanical properties predisposing to injury. Thus, if a younger cutoff for age of children (e.g., <14 years) was considered in our study, the results may have been different due to the levels of female sex hormones which affect the ligament laxity profile of females [20,23]. Relaxin which is released during the menstrual cycle affects collagen remodelling by reducing soft tissue tension in the ligament [20,23,24]. Comparisons between serum relaxin concentrations between men and women are poorly described in the present literature, however Wolf et al. previously found no statistically significant serum levels between genders [25]. Gender alone does not affect healthy knee laxity in isolation, as there are a lot of factors contributing to the level of ligament laxity such as, the delicate balance of hormonal levels, anatomic variations within individuals, pre-injury level of activity and dynamic neuromuscular balance [20].

Many studies have noted an association between elevated BMIs and the risk of noncontact ACL injuries [26–28]. As the BMI increases, the load borne across the knee increases along with joint space narrowing. Obese BMI patients have been known to sustain ligament injuries after a trivial low velocity injury as well [29]. Patients within the overweight and obese BMI range are a prominent cohort of patients who undergo repair for isolated ACL injuries or an associated multi-ligament tear. Anatomical differences, collagen integrity, and hormonal factors all play a role in contributing to healthy knee laxity [20]. Our study stratified patients into BMI categories based on height and weight without considering body mass composition, such as muscle mass and fat mass percentage which may play a role in the mechanism of ACL injuries. The number of patients in the obese category were underpowered and hence the true association of healthy knee laxity and obesity could not be ascertained from our cohort. In the study done by Zyroul et al., they found a strong association between BMI and knee laxity [20]. There appeared to be a negative association in men whereas in women a positive association was observed, although none of these observations were found to be statistically significant [20]. Kamarul et al. found in their study that height, weight, and age are not predictors of healthy knee laxity which correlates with the findings in our study which shows that BMI is not a predictor of knee laxity [21].

The findings of our study should be interpreted in the context of its limitations. Our study only investigated patients who had suffered an ACL injury previously and thus the findings of uninjured knee laxity values may not be reflective of an individual who has not sustained an ACL injury, as underlying patient factors such as collagen integrity and knee ligament laxity may be different between the groups [30]. Due to altered biomechanics and movement patterns post ACL injury, the uninjured knee has been proven to have a more anterior tibial station and increased internal tibial rotation as compared to the ACL-naïve population [17]. No other post-operative timepoint was considered for comparison to the 12-month mark in this study. Thus, reference values for healthy knee laxity for an ACL-naive Australian population still remains unreported. Radiological imaging was not performed to rule out the presence of ACL injury due to increase in cost to the participants involved in the study and attrition of the study population. There is a potential selection effect introduced due to inclusion of patients who got their 1-year post ACLR GNRB testing done for both the knees. The effect of BMI in our study was underpowered as only 35 patients were within the obese range and 9 patients in the underweight range. GJH was not assessed/taken as a covariate for analysis due to the subjective nature of the Beighton's score. Factors such as genetic predispositions, level of fitness, effect of exercise and sex hormone levels especially in females were not taken into consideration during our study. Our study only considered static demographic factors without accounting for the neuromuscular adaptive changes that occur post-injury in the ACL injured and uninjured knee. The analysis and influence of sex hormones on healthy knee laxity and specific genetic traits known to affect ligament and tissue laxity were not included in our present study, as compliance to multiple blood and DNA analysis would have yielded low participation amongst our large cohort, which we acknowledge was a significant limitation of our study. This limitation can be addressed in future studies to ascertain the effect of sex hormones on knee laxity values along with the effect of dynamic neuromuscular adaptive changes that occur post injury in the injured as well as the uninjured knee to get a true sense of the knee laxity values.

The most significant contribution from this study is the establishment of reference values of the contralateral uninjured knee laxity across different groups of age, gender and BMI in the ACL injured Australian population. To our knowledge, a study of this scale has not been done before in the ACL injured Australian population to ascertain the reference values of the contralateral uninjured knee laxity. This study does not determine the association of knee laxity and ACL injury risk as there is no non-ACL injured control population.

5. Conclusions

This study demonstrates that the contralateral uninjured knee laxity does not differ significantly between paediatric and adult patients, between males and females, and across different BMI categories in the ACL injured population. These findings challenge the assumption that age, sex, and BMI influence the uninjured knee laxity in the ACL injured population. Critically, this study establishes, for the first time, the reference values for contralateral uninjured knee laxity across age, gender and BMI subgroups in the ACL injured Australian population.

Author Contributions

S.A.K.: writing—original draft preparation, writing—reviewing and editing, data analysis and interpretation, supervision; V.Y.: writing—original draft preparation, writing—reviewing and editing; H.A.: conceptualisation, data curation, software, data analysis, writing—reviewing; A.S.N.: conceptualisation, supervision, methodology, writing—reviewing and editing, final approval of the version to be published. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was approved by the Northern Sydney Local Health District Human Research Ethics Committee (HREC/12/HAWKE/4). The original prospective data collection ethics application included clinical knee measurements, including ligamentous laxity. The protocol underwent subsequent revisions, with reapproval on 15 September 2017 (NSLHD reference: RESP/17/110; HREC reference: HREC/17/HAWKE/140). (NSLHD reference no.: HREC/17/HAWKE/140 and date of approval: 15 September 2017).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study. For the minors involved in the study, appropriate informed consent was obtained from the parents/guardians.

Data Availability Statement

Data will be available on reasonable request from our institutional data repository for 10 years post publication as per journal requirements. The data that support the findings of this study are not openly available due to participant privacy and consent limits and are available from ‘Sydney Orthopaedic Research Institute’ upon reasonable request.

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Conflicts of Interest

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

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