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The Relationship Between Generalized Joint Laxity and Hip Cartilage
Thickness in Ballet and Modern Dancers

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A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of
Master of Science

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ABSTRACT

The Relationship Between Generalized Joint Laxity and Hip Cartilage Thickness in Ballet and Modern Dancers

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Master of Science

Generalized joint laxity (GJL), a condition in which most joints of the body move beyond the accepted normal range of motion, is present in many ballet and modern dancers. It has been associated with an increased risk of injury, decreased muscle strength, and greater landing forces. Increased joint laxity results in joint instability and may precede the development of osteoarthritis, which is associated with a reduction in cartilage thickness. We hypothesized that dancers with GJL would have decreased hip cartilage thickness, as well as greater hip adduction angles and greater ground reaction force on landings. Twenty female ballet and modern dancers (mean age: 21.0 ± 1.79 years; mean weight: 57.0 ± 5.71 kg; mean years of dance experience: 14.6 ± 3.53 years; mean hours of training per week: 19.2 ± 7.24 hours) were recruited from college and local dance programs and screened for GJL. Each dancer performed three forward drop landings onto a force plate and received an MRI on their dominant hip. There was a significant difference in hip cartilage thickness, as viewed in the frontal plane (GJL group average: 2.66 ± 0.33 mm; control group average: 3.14 ± 0.48 mm; $p = 0.0160$), between the groups. There were no significant differences in peak hip adduction angle on landing (GJL group average: 80.9 ± 5.04 degrees; control group average: 77.9 ± 5.78 degrees; $p = 0.2269$) or peak landing ground reaction force (GJL group average: 5.56 ± 1.28 body weights; control group average: 5.17 ± 0.82 body weights; $p = 0.4274$) between the generalized joint laxity group and the control group. Dancers with GJL have thinner cartilage at the hip. These results suggest that dancers with GJL may be at a greater risk for injury. Therefore, these dancers may benefit from strength training programs, rather than flexibility training, to help counteract the joint instability that can lead to injury.

Keywords: generalized joint laxity, MRI, dancers, hip cartilage thickness

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Introduction

Generalized joint laxity (GJL) is a condition in which most joints of the body have a range of motion that is beyond the accepted normal.¹ Populations at an increased risk for GJL include young children,^{2,3} females,^{3,4} ballet dancers,^{3,5-7} and gymnasts.^{3,5} In a study by Deighan in 2005, it was found that 9.5 percent of a dancer population had hypermobility compared to 4.7 percent of the general population.⁸ This is thought to be due to inherent joint laxity that has been exaggerated by the demands of the sport.⁸ A case-control study in 1992 by Nilsson et al of 23 first-year ballet students found increased hypermobility and spinal flexibility in the dancers compared to age-matched controls.⁹ Another study by Gannon and Bird in 1999 found that participants in sports that focus on flexibility may be more likely to have GJL than the general population.⁵ GJL allows for greater flexibility, which may be beneficial to athletes in certain sports³ such as gymnastics and dance, and those at the highest levels of these sports have higher laxity levels than their novice peers.⁵

GJL, however, is a common finding associated with musculoskeletal complaints^{3,10} and is a risk factor for injuries³ such as sprains, subluxations, and dislocations.¹⁰ Malalignment from joint laxity can lead to cartilage loss¹¹ and a lack of joint stability may adversely influence joint mechanics.¹² Those with GJL are also at a greater risk for premature osteoarthritis,¹¹ muscle strength and proprioception deficits,³ and capsular laxity at the hip.¹³ Hip capsular laxity, which is commonly seen in individuals with GJL,¹³ can in turn lead to dislocations, labral tears, and articular cartilage damage.¹¹

Hip injuries represent a source of great disability in the general population¹⁴ and among athletes, especially in sports involving repetitive external hip rotation with axial loading¹⁵ such as gymnastics, dancing, and figure skating. Hip joint instability and impingement are the most

common biomechanical risk factors for premature arthritis at the hip joint.¹⁶ Joint instability can place abnormal forces on the hip, leading to deformities or tears of both the hip capsule and labrum.¹⁷ Capsular laxity is often seen in individuals with GJL¹³ which can be the result of a collagen abnormality or secondary to overuse or repetitive activities, as is commonly seen in athletes.¹³ Ligamentous laxity puts the individual at an increased risk for hip instability, dislocation, and labral tears.¹³

There are currently no devices to directly measure hip joint laxity; however, it has been shown that individuals with GJL also have greater hip joint laxity.¹⁸ The Beighton tests have gained global acceptance and appear to be the most used tests for diagnosing general joint hypermobility.⁴ There is no universal agreement on the point threshold for hypermobility, but studies have commonly used 5 or 6 points out of 9 to classify an individual as having GJL.¹⁰ In a study by Juul-Kristensen et al scores of greater than or equal to 6 were found to have a result of “good to excellent” with regards to reproducibility of a GJL diagnosis.⁴ In this same study, it was found that the reproducibility of diagnosing GJL was high, with a kappa score of approximately 0.74, and that the Beighton tests for GJL also showed high reproducibility, with a kappa score above 0.80.⁴ Other studies have also used a Beighton score cutoff of 6 when determining if an individual has GJL.¹⁹

To assess cartilage health and thickness at the hip, studies have used MRI.^{20,21} Several methods have shown that cartilage thickness can be accurately measured without the use of contrast or external devices.^{20,22,23} MRI has also been used to show changes in hip cartilage volume between populations, including healthy and obese adults.²⁴ Cartilage loss over time related to joint laxity has been studied at the knee,¹² but its effect on cartilage at the hip is unknown.

Individuals with GJL often have a high passive-to-active range of motion ratio, indicating joint instability and/or muscle strength deficits.⁸ People with GJL may also experience proprioception deficits.⁸ Studies have shown that joint laxity is negatively correlated to strength.²⁵ Hip strength is related to differences in hip adduction angles on landing.²⁶ Weaker muscles around the hip are related to greater hip external adduction moments.²⁶ It has also been found that individuals with stronger muscles about the hip and knee have lower peak vertical ground reaction forces than those with weak muscles.²⁶ Ground reaction forces have been implicated in injury to the lower extremities²⁷ and have been linked to the onset and development of osteoarthritis.^{28,29}

The purpose of this study was to evaluate differences in hip cartilage thickness between ballet and modern dancers with GJL and dancers without GJL, and to evaluate differences in peak hip adduction angle and peak ground reaction force on landing between dancers with GJL and those without GJL. We hypothesized that the GJL group would have decreased hip cartilage thickness compared to the control group. We also hypothesized that the GJL group would have higher peak hip adduction angles and higher peak ground reaction force on landing. Examining risk factors that may be associated with decreased hip cartilage volume may assist in the creation of interventions that postpone or eliminate the development of hip osteoarthritis.²⁴ This study will provide information about the relationship between GJL and hip cartilage thickness that may assist in preventing hip injuries in athletes with GJL.

Materials and Methods

Research Design

This was a cross-sectional study. Healthy female ballet and modern dancers, ages 18–25, were selected for participation. Dancers were divided into 2 groups: GJL subjects and controls. Comparisons were made between the groups.

Subjects

A convenience sample of twenty healthy female volunteers (age = 21 ± 1.8 yrs, height = 1.65 ± 0.07 m, weight = 57.0 ± 5.71 kg), similar to subject numbers used in studies by Mosher et al³⁰ and Hodler et al³¹ were selected for testing. Subjects were recruited from the Dance Department at Brigham Young University and other local dance studios. Subjects were screened for GJL and 10 subjects with GJL were selected. Twenty-two additional subjects were screened and 10 of these subjects, who best matched the GJL group, were recruited as controls for the GJL subjects, matched for the group variables of height, weight, years of experience, and average hours of training per week (Table 1). All subjects were ballet or modern dancers at the highest level at their studio. Participants had trained consistently for the 3 months prior to collection and had never experienced any of the following exclusion criteria: a medical or allied health professional diagnosis of hip cartilage injury or hip osteoarthritis, a previous hip injury involving surgery (including arthroscopy), or any contraindication to MRI, including pregnancy, metal sutures, or claustrophobia.

Table 1. Participant descriptive variables

	GJL (SD)	Control (SD)
Age (years)	20.1 (1.85)	21.8 (1.32)*
Height (m)	1.67 (0.04)	1.62 (0.09)
Body mass (kg)	57.0 (6.07)	57.0 (5.67)
Years of participation	14.5 (3.24)	14.7 (3.97)
Average activity per week (hrs)	18.6 (7.39)	19.8 (7.44)
Beighton Score	7.80 (1.23)	1.70 (0.95)*

*p < 0.05 from mean of GJL group

Participants completed an informed consent form prior to participation. The Institutional Review Board at Brigham Young University approved this study. Potential subjects were prescreened for participation to verify that they met age and level qualifications and were MRI eligible.

Beighton Score Screening

Participants were screened for GJL using the Beighton Scale for joint laxity. The Beighton score gives a point for each side of the body for each of the following conditions: passive extension of the 5th metacarpophalangeal joint past 90 degrees, passive apposition of the thumb to the forearm, hyperextension of the elbow past 10 degrees, hyperextension of the knee past 10 degrees, and trunk flexion that allows the palms to be placed flat on the floor.¹⁰ A score of 6 or more qualified them for the GJL group. Each participant had his or her score recorded, along with his or her age, height, mass, years of experience, and hours spent training per week. The non-GJL group was matched for height, mass, years of experience, and hours spent training per week with the GJL group.

MRI Data Acquisition

Each participant had an MRI performed on their dominant hip, defined as the normal landing leg, or the leg used to kick a ball if no preference during landing. MRI data were collected at the MRI Research Facility at Brigham Young University. Hips were imaged on a Siemens TIM-Trio 3.0T MRI scanner (Siemens, Erlanger, Germany). The subject was positioned head first supine in the magnet, with a flex coil strapped around the hip. The participant had her feet attached to a board and hips strapped down to eliminate excessive movement and provide a consistent hip position across subjects. MRI data was acquired following a localizer scan. Sagittal and frontal images were obtained using a T₂-weighted fat-suppressed three-dimensional gradient-recalled acquisition sequence in the steady state, as was previously used in a study by Teichtahl et al in 2015.²⁴ The sagittal scan had the following criteria: repetition time 14.45 msec, echo time 5.17 msec, flip angle 25 degrees, slice thickness 1.5 mm, field of view 16 cm, pixel matrix 320 x 320, acquisition time 7 minutes 47 seconds, and one acquisition.²⁴ The frontal scan had the following criteria: repetition time 3,400 msec, echo time 64 msec, flip angle 90 degrees, slice thickness 3 mm, field of view 16 cm, pixel matrix 256 x 256, acquisition time 5 minutes 26 sec, and one acquisition.²⁴

Drop Landings

Participants performed 3 forward drop landings onto a portable force plate (Bertec Corporation, OH, USA). Participants were unshod, dropped from a height of 40 cm, and landed on one foot. Subjects were instructed to land on their dominant leg as normally as possible, without falling, stepping off the force plate, or touching down with the opposite foot or either hand. Subjects had 3 markers attached directly to their clothing at the right ASIS, left ASIS, and on the patella of the dominant leg to calculate peak hip adduction angle, similar to a study by

Maykut et al.³² These landings were filmed and hip adduction angles from the trials were analyzed and averaged for each subject.

Data Analysis

Articular cartilage thickness was measured using the software Analyze 12.0 (AnalyzeDirect, Inc., KS, USA). One mid-sagittal image and one mid-frontal image were used for each subject. The images used for measurements were the images that were the closest to the center of the femoral head. Five measures of cartilage thickness were made on each image, totaling 10 measurements per subject. These measurements were taken at the midpoint of the femoral head and at 2 points on each side of the midpoint. All 5 measurement points were equidistant apart. The full thickness was measured using a spline tracing (Figures 1, 2) around both the femoral and acetabular cartilage in both planes. These 10 points were then averaged to obtain one value of cartilage thickness for each subject.

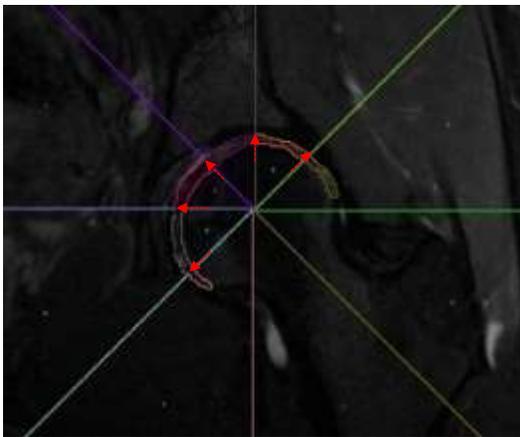


Figure 1. Frontal view of hip cartilage thickness. A spline tracing was created around the acetabular and femoral cartilage. Five even divisions were created along the spline tracing and thickness measurements were taken at the locations of the arrows.

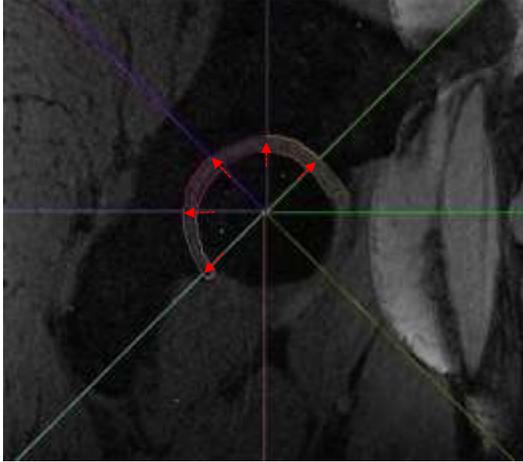


Figure 2. Sagittal view of hip cartilage thickness. A spline tracing was created around the acetabular and femoral cartilage. Five even divisions were created along the spline tracing and thickness measurements were taken at the locations of the arrows.

Hip angles in the frontal plane were determined using the 2D video analysis software, Kinovea (version 0.8.15). The peak hip adduction angles from each of the 3 trials were determined by creating an angle between the non-landing hip, landing hip, and landing knee (Figure 3). These three values were then averaged, giving one value per subject. Landing ground reaction forces from the force plate were recorded and the peak ground reaction force for each landing was found. These three forces were also averaged to give one value for each subject.



Figure 3. Participants landed on one foot from a height of 40 cm onto a portable force plate. The peak hip adduction angle was measured, using markers attached to the left ASIS, right ASIS, and patella of the landing leg.

All analyses were performed by the same researcher, who was blinded to the group assignment of the subject. MRI data sets were labeled to exclude any identifying subject variables and drop landings were only recorded from the waist down.

Statistical analysis was performed using SAS statistical software (version 9.4, SAS Institute, Inc., Cary, NC). T-tests between groups were performed to determine if there were group differences between age, height, mass, years of experience, or hours of dance participation per week (Table 1). T-tests were also performed to determine if there was a statistically significant difference in cartilage thickness, peak force of landing, and peak hip adduction angle between the two groups. A p-value of less than 0.05 was used to determine statistical significance.

Results

MRI Hip Cartilage Thickness

Average hip cartilage values are presented in Table 2. In the sagittal plane, we did not find any significant differences in the average cartilage thickness between groups ($p = 0.6213$). However, in the frontal plane, there was a statistically significant difference in cartilage thickness ($p = 0.0160$). There was also a significant difference in overall cartilage thickness, with all 10 points averaged, between the GJL and non-GJL groups ($p = 0.0163$). These differences suggest a decrease in average cartilage thickness in GJL subjects.

For each subject, 5 measure of thickness were taken in both the frontal and sagittal planes. These values were averaged for each subject, then across each group and compared for differences. Frontal and sagittal cartilage thickness measures were also averaged to give a total cartilage thickness for each group.

Table 2. Cartilage thickness values (mm).

	GJL (SD)	Control (SD)
Frontal	2.66 (0.33)	3.14 (0.48)*
Sagittal	3.96 (0.40)	4.05 (0.41)
Total	3.31 (0.26)	3.59 (0.22)*

* $p < 0.05$ from mean of GJL group

Landing Ground Reaction Force and Hip Adduction Angle

Values for peak ground reaction force of landing and peak hip adduction angle were compared between the GJL and non-GJL groups. There was not a significant difference in peak ground reaction force of landing between the groups ($p = 0.4274$; Table 3). There was not a significant difference in peak hip adduction angle between the groups ($p = 0.2269$; Table 4).

Each subject performed 3 drop landings from a height of 40 cm onto a portable force plate. Values were averaged to give one value per subject, then averaged across each group and compared for differences.

Table 3. Peak Landing Ground Reaction Force (normalized by body weights).

	GJL (SD)	Control (SD)
	3.65 (0.93)	4.14 (0.13)
	4.24 (0.83)	4.25 (0.37)
	4.71 (0.32)	4.42 (0.62)
	4.88 (0.31)	4.71 (0.55)
	5.02 (0.57)	4.89 (0.81)
	5.94 (1.36)	5.28 (0.96)
	6.14 (1.18)	5.37 (0.30)
	6.17 (1.25)	6.03 (0.24)
	7.17 (0.54)	6.19 (0.15)
	7.65 (0.71)	6.39 (1.21)
Group Average	5.56 (1.28)	5.17 (0.82)

Each subject performed 3 drop landings from a height of 40 cm. Markers were placed on the left ASIS, right ASIS, and patella of the landing leg. Peak hip adduction angle was measured for each landing. Values were averaged to give one value per subject, then averaged across each group and compared for differences.

Table 4. Peak Hip Adduction Angle (degrees).

	GJL (SD)	Control (SD)
	72.0 (3.00)	69.0 (2.00)
	73.7 (4.16)	72.0 (5.29)
	79.0 (4.36)	73.7 (2.51)
	79.7 (1.53)	75.7 (2.52)
	80.7 (3.06)	76.3 (6.81)
	82.7 (1.53)	78.0 (5.29)
	84.0 (4.00)	78.3 (1.53)
	84.3 (4.73)	84.7 (1.53)
	85.0 (4.00)	85.3 (4.04)
	88.0 (2.00)	85.7 (0.58)
Group Average	80.9 (5.04)	77.9 (5.78)

Discussion

We hypothesized that dancers with GJL would have less cartilage thickness than controls. We found that there was a significant difference in total cartilage thickness between the GJL and control groups ($p = 0.016$), with an average group difference of 0.28 mm. There was not a statistically significant difference in thickness in the sagittal plane ($p = 0.621$), with a difference of only 0.09 mm. However, there was a significant difference in cartilage thickness in the frontal plane ($p = 0.016$), with an average group difference of 0.48 mm (Table 2). A possible explanation for this difference in results between frontal and sagittal thickness could be the unbalanced stretching that dancers perform.³³ When told to warm up, dancers spent a majority of time on hip abduction and external rotation, with less focus on adduction, flexion, or extension.³³ This focus on frontal plane movement could account for the discrepancy in cartilage thickness differences. Since dancers are putting more stress on the hip in the frontal plane, it follows that there could be less cartilage in that plane in dancers with a greater range of motion.

The mean thickness of the combined acetabular and femoral cartilage is 2.33–3.24 mm for healthy individuals (ages 19-53).²³ It is difficult to differentiate between the acetabular and femoral cartilage on MRI, so we looked at combined values. It is thought that laxity may relate to a loss of cartilage and precede osteoarthritis.¹² This loss of cartilage can be accompanied by joint surface or subchondral bone damage and can lead to chronic pain, a loss of joint mobility, and effusions.³⁴ In a systematic review, it was found that there is moderate evidence of an association between sporting activities and hip osteoarthritis, but this may be related to other confounding variables between athletes and nonathletes.³⁵ Indirectly, there is evidence that joint laxity is a risk factor for the development of premature osteoarthritis.³⁶ Ligamentous joint laxity leads to joint instability, making individuals with GJL more vulnerable to the effects of

overuse.³⁶ Osteoarthritis is a result of joint use and joint vulnerability,³⁷ and thinning cartilage is associated with osteoarthritis.³⁸ It has been shown that professional ballet dancers had a greater incidence of acetabular cartilage thinning and tears (75% of subjects) compared to active healthy controls (28%),³⁹ but these subjects were not screened for GJL. Naish et al showed that a difference of 0.05 mm between groups was statistically significant,⁴⁰ and studies have shown that osteoarthritis patients see an average decrease in joint space width of 0.1–0.15 mm annually,⁴¹ indicating that small changes in thickness can be important to joint health.

Since joint laxity has a negative correlation to strength²⁵ and individuals with stronger muscles about the hip and knee have lower peak vertical ground reaction forces than those with weak muscles,²⁶ we hypothesized that dancers with GJL would experience greater hip adduction and more ground reaction force when landing. However, we found no difference in hip adduction angle or peak ground reaction force of landing between the GJL and control groups (Tables 3, 4). We noticed no differences in landing kinematics between the groups in the frontal plane, but did not view movements in other planes. Although we did not compare strength measures between the groups, we believe the similarity between groups is due to dancers' training and technique. Dancers are expected to control their landings and to land softly. Because of this, they have learned to better activate lower extremity muscles to control landings, thus decreasing their ground reaction forces.²⁹ This muscle strength is often missing in the general population of GJL subjects,²⁵ leading to greater hip external adduction moments.²⁶ We did not determine forces at the hip directly, so we are unsure if this decrease in ground reaction force caused a decrease in forces at the hip, or if other joints, such as the knee or ankle, played a role. Dancers have exceptional balance, due to years of training and strength.⁴² In studies comparing dancers to nondancers, it was observed that dancers are better able to maintain

upright balance in standing^{42,43} and when landing from a jump.⁴³ Dancers are trained in technique, so we do not believe that dancers with GJL altered their landing kinematics to attenuate forces before they arrived at the hip. We had subjects land on their dominant leg, the leg that they were most comfortable landing on or the one used to kick a ball if no preference during landing, so they were able to activate muscles around the hip joint to control the landing, similar to what they experience in their normal training.

This study recruited subjects from a convenience sample of female, college-aged dancers at and around Brigham Young University, so findings cannot be generalized to the entire population of dancers. The hip adduction measures were viewed only in the frontal plane, so these measures could be influenced by sagittal and transverse plane hip and knee angles. The possible rotation in the transverse plane and flexion in the sagittal plane could have altered the hip adduction angle, implying that a 3D analysis of hip adduction may give more accurate results. The analysis of MRI data using Analyze Direct involved using a spline tracing. All tracings were performed by the same investigator, making it reliable across subjects, but spline tracings are not entirely accurate for measures of thickness. The tracing went around the edge of the cartilage, so measures are likely slightly larger than the actual thickness. However, it is difficult to compare values between studies as MRI data has some variance. We also did not measure the thickness around the entire band of cartilage. We instead chose to use ten points around the center of the femoral head in the frontal and sagittal planes. There is slight variation in the anatomy of the hip between subjects; however, we felt these 10 points provided an accurate representation of the average cartilage thickness of each subject.

This study has shown that hip cartilage thickness is decreased in dancers with GJL compared to controls and these differences are comparable to changes seen with osteoarthritis.⁴¹

Dancers generally experience overuse injuries,^{44,45} especially in the lower extremities,⁴⁴ which can be harmful to their training and careers. It has been suggested that younger dancers prone to joint laxity should be identified and protected from overstretching,⁴⁶ and this study supports that idea. This study also suggests that dancers with GJL have altered training programs to focus on controlling their movements rather than focusing on flexibility. Dancers with GJL will still need to perform movements that put their bodies in compromising positions as part of their training and career, but care should be taken to limit extreme movements in practice in order to preserve cartilage thickness.

Conclusion

This study provides more information about how GJL affects hip cartilage thickness. GJL is associated with decreased hip cartilage thickness. Our results suggest that dancers should be screened for GJL and alternative training programs should be implemented to focus less on flexibility training and more on stabilizing the joint to help prevent injuries. There was not a significant difference in peak landing ground reaction force or peak hip adduction angle on landing. This is most likely because dancers are trained to control their movements on landings.

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