



Letter to the Editor

Normalization influences knee abduction moment results: Could it influence ACL-injury research, too? Response to Letter to the Editor by Dr. Timothy E. Hewett



Dear Editor,

Thank you for the opportunity to respond to Dr. Timothy E. Hewett's Letter to the Editor¹ concerning our 2017 study entitled "Normalization influences knee abduction moment results: Could it influence ACL-injury research, too?".² While I was not surprised that the findings of our investigation would precipitate a response, I was discouraged to see: (1) a lack of any evidence-based rationale; (2) a misleading characterization of his 2005 study³ that implied that our call to confirm that his prospective findings would be the same using normalized kinetic data was not warranted; and (3) ambiguity with respect to Dr. Hewett's views on normalization. Accordingly, I believe it is necessary to provide readers with additional context relative to these three points that they should take into consideration when evaluating the merits of our 2017 study and the content put forward in the Letter to the Editor.

Dr. Hewett's call for clinicians and researchers to "be aware that normalized forces and moments do not exist in nature [...] and are merely derived calculations" coupled with the unsupported claim that "[a]ctual and real (absolute value) forces and moments [...] are what actually rupture ligaments"¹ is an alarming oversimplification that does not capture the inherent limitations of inferring the magnitude of anterior cruciate ligament (ACL) loading from net joint moments and forces calculated using a traditional inverse dynamics approach. Furthermore, Dr. Hewett seeks to have readers summarily dismiss normalized forces and moments for not being "real" without addressing the underlying rationale for why normalization is necessary when making between-subject comparisons. It is essential to recognize that no net force or moment – normalized or otherwise – calculated using inverse dynamics directly injures the ACL. Rather, like all biologic tissues, the ACL is injured when it experiences excessive internal stress that causes strain (deformation) beyond the ACL's physiological limit of failure. Moreover, the magnitude of ACL stress (σ) is not simply a function of the force (F) applied to the ACL, but it is also dependent upon the ACL's cross-sectional area (CSA) ($\sigma = \frac{F}{CSA}$). As it is generally not possible to directly measure ACL force *in vivo*, researchers must use surrogate measures, such as net external knee abduction and flexion moments, and anterior tibial shear force that are known to load the ACL,^{4–6} to make inferences about the actual magnitude of force being applied directly to the ACL. However, contrary to the assertion of Dr. Hewett, "real (absolute value)" magnitudes of these surrogate biomechanical variables do not provide accurate insight into the amount of ACL stress – which is what actually causes ACL strain and leads to ligament rupture – because these "real (absolute value)" moments and forces do not account for the CSA of the

ACL. This notion is best supported by Lipps et al.⁷ who observed that ACLs with *lesser* CSA exhibited *greater* relative strain despite the application of the *same absolute magnitude* of knee flexion and abduction moments. Additionally, previous investigations have documented that greater height⁸ and mass⁹ are related to greater ACL CSA/volume. Therefore, the benefit of normalizing forces and moments (as surrogates for ACL force) by height and/or mass (as surrogates for ACL CSA) is to obtain a more accurate estimate of the magnitude of ACL stress. I believe that this evidence-based rationale provides readers with a solid conceptual model in support of the need to normalize forces and moments and, combined with our 2017 findings², makes evident why normalization is absolutely necessary when making any between-subject comparisons.

I also believe Dr. Hewett's statement that "[t]he study that was conducted and published in AJSM in 2005 did calculate and analyze normalized moments as Norcross et al. suggest"¹ is at best misleading because this publication does not contain results using non-normalized moments.³ However, this statement, coupled with Dr. Hewett's admission that "normalized moments did not predict subsequent ACL [injury]. . . while absolute value moments did"¹ indicates that the researchers did in fact explore both normalized and non-normalized data when conducting their 2005 analyses. Unfortunately, this fact was not reported in the original article and, to my knowledge, the scientific community was not made aware of the additional analyses and that normalized moments were not predictive of subsequent ACL injury until April 2017¹⁰ – after we had conducted and published our study.²

Finally, I find Dr. Hewett's position with respect to normalization to be extremely ambiguous. In the Letter¹, he states that: (1) "normalized moments and forces. . . are merely derived calculations"; (2) "it is a good idea to normalize forces and moments to compare between populations that differ in anthropometric features such as height and weight"; and (3) "normalized forces and moments are likely invalid for prediction of future injury risk". The inherent contradictions in these three statements notwithstanding, there are numerous examples in Dr. Hewett's publication record that are inconsistent with these stated views. For instance, he has: (1) compared normalized moments between groups that *did not* differ in height and mass^{11–13}; (2) compared non-normalized moments between groups that *did* differ in height and mass^{14–16}; and (3) used either non-normalized³ or normalized¹⁷ moments in logistic regression models to predict future injury risk. While there may be alternative explanations for why normalization was or was not applied in each of these instances, the methods used are seemingly at odds with his views regarding normalization put forward in the Letter to the Editor.

I commend Dr. Hewett for the significant contributions that he has made to improve our understanding of ACL injury, and believe that he deserves tremendous credit for the work that his research group has done and continues to do to advance ACL injury reduction initiatives. However, I also believe that it is important to contribute

to an open and constructive exchange on points of disagreement in the hope that the scientific community can use the best available evidence to support our common goal – meaningful reductions in ACL injury risk for athletes across the world.

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