Level V Evidence

Shoulder Range of Motion Measurements and Baseball Elbow Injuries: Ambiguity in Scientific Models, Approach, and Execution is Hurting Overhead Athlete Health

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Abstract: Elbow injuries are a significant and increasing issue in baseball. Elbow injuries account for 16% of all injuries sustained at the professional level and collegiate level. Because of the continued rise in injury rates, loss of performance value, and medical burden, sports medicine clinicians have attempted to research the causes underlying this injury epidemic in an attempt to help mitigate baseball elbow injuries. Shoulder range of motion (ROM) is the most researched clinical metric related to elbow injuries in baseball and has the greatest consensus as a viable prognostic factor specifically for medial elbow injury. Shoulder ROM is easy to measure, can be modified through stretching and manual therapy interventions, and can be easily assessed during preseason screening throughout all baseball levels. Despite a large number of studies and the widespread use of shoulder ROM in injury risk screening, current findings are unclear as to whether there is a true cause-effect relation with baseball elbow injuries. We argue that the conflicting findings revolving around the value of shoulder ROM measurements associated with baseball elbow injuries are the result of 4 gaps in the research approaches implemented to date: ambiguous research questions, mixed study populations, statistical models used, and shoulder ROM methodology. Specifically, there is a mismatch of methods, statistical models, and conclusions such as (1) investigating the association (i.e., correlation) between shoulder ROM measurements and injury and (2) investigating the cause-effect relation of shoulder ROM to baseball injuries. The purpose of this article is to detail the required scientific steps to evaluate whether preseason shoulder ROM is a potential causal factor for pitching elbow injury. We also provide recommendations to allow for future causal inferences to be made between shoulder ROM and elbow injury. This information will ultimately assist in informing clinical models of care and decision making for baseball throwers.

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Elbow injuries are a significant and increasing issue in baseball.[1-5] Elbow injuries account for 16% of all injuries sustained at the professional level and collegiate level.[2] These injuries result in a high medical burden, costing Major League Baseball $395 million over a 10-year span, at $1.9 million per player.[6] The median time to return from ulnar collateral ligament reconstruction is 17 months.[3] Because of the continued rise in injury rates,[2,4] loss of performance value,[7] and medical burden,[6] sports medicine clinicians have attempted to research the causes[8-10] underlying this injury epidemic[11] in an attempt to help mitigate baseball elbow injuries.[12,13]

Shoulder range of motion (ROM) is the most researched clinical metric related to elbow injuries in baseball[9,14] and has the greatest consensus as a viable prognostic factor specifically for medial elbow injury.[15,16] Shoulder ROM is easy to measure,[12] can be modified through stretching and manual therapy interventions,[17,18] and can be easily assessed during preseason screening throughout all baseball levels.[9] Despite a large number of studies[9,14] and the widespread use of shoulder ROM in injury risk screening,[15,16] current findings are unclear as to whether there is a true cause-effect relation with baseball elbow injuries. In a 2018 meta-analysis of 3 studies, shoulder internal rotation and total rotation (external rotation plus internal rotation) were identified as injury prognostic factors whereas external rotation was not.[14] In contrast, a 2020 meta-analysis of 3 studies identified shoulder external rotation as an injury prognostic factor but found that shoulder internal rotation and total rotation were not injury prognostic factors.[9] Since these publications, further studies have evaluated this issue, with conflicting results between clinical values of shoulder internal rotation, external rotation, total rotation, and shoulder flexion ROM.[19-21] Despite these extensive efforts, we continue to see conflicting findings that make it difficult to provide clear clinical recommendations.

We argue that the conflicting findings revolving around the value of shoulder ROM measurements associated with baseball elbow injuries are the result of 4 gaps in the research approaches implemented to date: ambiguous research questions, mixed study populations, statistical models used, and shoulder ROM methodology. Specifically, there is a mismatch of methods, statistical models, and conclusions such as (1) investigating the association (i.e., correlation) between shoulder ROM measurements and injury and (2) investigating the cause-effect relation of shoulder ROM to baseball injuries. The purpose of this article is to detail the required scientific steps to evaluate whether preseason shoulder ROM is a potential causal factor for pitching elbow injury. We also provide recommendations to allow for future causal inferences to be made between shoulder ROM and elbow injury. This information will ultimately assist in informing clinical models of care and decision making for baseball throwers.

Implications of Ambiguous Scientific Methods in Understanding Causal Relations

Ambiguous scientific models and methods result in inaccurate conclusions and clinical recommendations with unintended clinical consequences. Unfortunately, these mistakes are repeated in multiple studies, leading to a "canonization of false facts"[22] that are difficult to change in research and clinical practice. To provide a brief hypothetical example, ice cream consumption is associated with drowning. In reaction to these findings, the government bans ice cream sales. This action holds little hope of reducing the mortality rate because the causal factor is the sunny weather during the summer season that increases both the number of persons who swim in open water and the volume of ice cream eaten. Unfortunately for baseball clinicians, we are at a much earlier stage of our understanding and cannot yet infer any treatment strategies from studies that show an association between shoulder ROM measures and elbow injury because it is unclear whether there are other factors that explain the relation between shoulder ROM and elbow injury. Better research designs, such as assessing how humeral torsion affects clinical shoulder ROM measurements,[23] can bring us closer to meaningful treatment inferences.

The discussion of association versus causation has strong implications on clinical examinations, screening, and interventions. Understanding the potential true causal relations between shoulder ROM and medial elbow injury allows sports medicine clinicians to refocus on the important causative factors—and to discard irrelevant information. In a brief clinical example, much of the more recent baseball medical literature has discussed the importance of shoulder external rotation and flexion over shoulder internal rotation as important prognostic markers.[19] In a hypothetical example, through careful causal study, shoulder external rotation was found to have a true strong positive causal relation to medial elbow injuries (i.e., greater external rotation increases elbow injury likelihood). Furthermore, shoulder internal rotation was not found to have a causal effect on elbow injuries. As a result, clinicians would provide interventions that focus on providing shoulder external rotation end-range stability and maintaining preseason external rotation levels.[24] However, if shoulder internal rotation is identified as a causal factor, and external rotation is not, then the clinician will prescribe posterior shoulder

Table 1. Definitions

Term	Definition	Clinical Example
Association	A statistical relation between a factor and an event or outcome, which must have a specified direction and magnitude[32]	People who drink coffee are more likely to receive a diagnosis of cancer.[33]
Causality	A certain factor contributes to (i.e., causes) an event if, without this factor, the event would not occur[29]	A bacterial infection causes a fever. Without the bacterial infection, no fever would appear.
Prediction	Mathematical models (i.e., equations) that include multiple factors that forecast the risk or probability of an undiagnosed condition (diagnostic) or future outcome (prognostic)[34] Prediction models include both causal and non-causal factors.	The Framingham heart disease prediction model was developed to predict the risk of sustaining coronary cardiovascular disease.[35]
Secondary terms		
Confounder	A variable that is a common cause of the exposure (or factor) of interest and the outcome[30]	Coffee drinkers are more likely to smoke cigarettes. When cigarette consumption is controlled for as a confounder, there is no relation between coffee drinking and cancer.[33]
Prognostic factor	A factor that is associated with a future clinical outcome in persons with a baseline disease, condition, or health state[36] Prognostic factors must precede the outcome and can be causal or non-causal but do not have to be biologically plausible.	A high cholesterol level is a prognostic factor for myocardial infarction. A high cholesterol level precedes the outcome and is biologically plausible.
Conditioning (also known as controlling or adjusting)	Disconnecting a factor from its associations (or causal effects) between $\geq$2 other factors[31,37] This can be performed through stratification, sub-classification, or adjustment.	Conditioning on the confounder humeral torsion blocks the backdoor path between shoulder range of motion, humeral torsion, and elbow injury. This allows the causal effect from shoulder range of motion and elbow injury to be assessed.
Directed acyclic graph	A graph that forms a directed path between a factor and an outcome to help clarify the potential causal relations This graph cannot have a continuous feedback loop.[37]	A DAG is presented in Figure 1.

manual therapy,[18] as well as daily posterior shoulder stretching,[18,24] and will discard shoulder external rotation end-range stability. Although this is only a brief and simple (and one would argue a reductionist) example, it demonstrates the importance of the minutia and semantics. Knowing the true causal structure allows clinicians to identify measures and interventions and focus their efforts to impact patient outcomes.

Defining Association, Causality, and Prediction

An "association" is defined as only a statistical relation between a factor (e.g., shoulder ROM) and an outcome (e.g., elbow injury).[25] Associations do not account for other effects. Associations are valuable and provide the foundation for future hypotheses.[26] Associations cannot (and should not) provide information regarding clinical intervention because there may be other reasons (factors) "why" associations exist.[25] Many times, clinicians think of an association as solely a correlation; however, a correlation is a subset of associations. A correlation, although broadly accurate, can miss important details, as seen in the spurious example of ice cream and drowning. Closer to home, coaches and medical staff once believed that water consumption during exercise caused cramping owing to the observed correlation between athletes drinking and experiencing cramping. It transpired that those drinking more were at higher risk of heat illness and subsequent cramping.[27] Restricting water consumption during practice increased the risk of cramping (and that of heat illness).[28]

"Causality" is the true cause-effect relation between a factor and an outcome.[29] This relation is extremely sensitive to the effects of other factors (e.g., confounders) and other research biases (Table 1).[30] Causal factors can be used to identify potential interventions.[38]

Causality must start with a specific causal question, which can be informed through the aid of a proposed

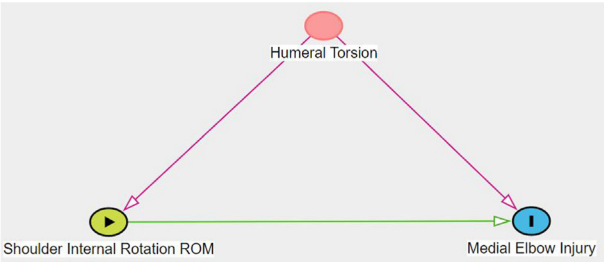

Fig 1. Simple directed acyclic graph. Shoulder internal rotation range of motion (ROM) has a direct effect on medial elbow injuries, shown through the directed arrow. However, this effect is mitigated by the confounder humeral torsion, shown with arrows stemming from humeral torsion to both shoulder internal rotation and medial elbow injury. Until humeral torsion is controlled for (also known as "conditioning" or "adjusting") to block the effect on both shoulder internal rotation and medial elbow injury, the true direction and magnitude of the causal relation cannot be determined. It is important to note that this directed acyclic graph infers 2 hypotheses that can be tested with observational studies: Humeral torsion should be associated with both shoulder internal rotational ROM and medial elbow injury, and shoulder internal rotation ROM should be associated with medial elbow injury. Regression analyses, for example, can give weights to these associations, along with statistical significance.

(theoretical) causal model, drawn with directed acyclic graphs (DAGs) (Table 1, Fig 1). DAGs are pictorial models of a plausible underlying causal structure that consist of nodes (i.e., factors) and edges (i.e., arrows) that work unidirectionally.[39] These diagrams can assist in identifying what factors to measure and control for when designing a study to answer a specific causal question.[39] There is robust literature on DAGs,[31,39,40] with many tutorials to further understand DAGs.[41,42] Within the simple example in Figure 1, shoulder internal rotation ROM has a direct effect on medial elbow injuries, shown through the directed arrow from shoulder internal rotation to medial elbow injury. However, this effect is mitigated by the confounder of humeral torsion, shown with arrows stemming from humeral torsion to both shoulder internal rotation and medial elbow injury. Until humeral torsion is controlled for (also known as "conditioning" or "adjusting") to block this specific effect on both shoulder internal rotation and medial elbow injury, the true direction and magnitude of the causal relation cannot be determined.

Required Methods to Evaluate Whether Preseason Shoulder ROM Is a Causal Factor for Medial Elbow Injuries in Baseball Players

To investigate whether preseason shoulder ROM is truly a causal factor for medial elbow injuries, specific methods are needed within the context of sport and baseball. The gold standard for assessing causality is the randomized controlled trial (RCT).[43] However, RCTs are difficult to perform and may be unethical in the sports setting for many reasons. Adherence or uptake could be limited because competing sports clubs may not want to contend with being randomized into the "control" group, potentially losing a competitive advantage.[44] To assess specific causal questions about injuries, it is unethical to randomize athletes into "hurt" and "healthy" groups.[45] It would be impractically difficult to randomize athletes into groups to have more or less shoulder ROM, providing further infeasibility of the RCT design.

Previous research has identified arm injury prevention programs as effective in mitigating injury risk in baseball players.[12,13] As a result, it is unethical to not provide arm injury prevention programs to all study participants. Although a hybrid RCT (e.g., wedge design) is a viable method to overcome this obstacle,[46] this still does not evaluate shoulder ROM as a causal factor in relation to baseball elbow injuries. This is because injury prevention programs must provide interventions on both shoulder ROM and strength to be ethically sound.[12,13] Consequentially, intervention programs can investigate an injury prevention program's effectiveness in reducing arm injuries but cannot isolate shoulder ROM (or shoulder strength) as a causal factor.

Table 2. Positive and Negative Implications for Methods to Assess Causal Relations in Sport

Method	Positive Implications	Negative Implications
Randomized controlled trial	Putative allocation of treatment and control Clear identification of causal effects	Not generalizable Possibly infeasible in sport (i.e., competitive advantage) Possibly unethical (i.e., athletes cannot be randomly injured)
Observational causal inference	Generalizable Ethical and feasible	Requirement for massive amount of data Unobserved confounding, which may not allow control of all important confounders Possible lack of consensus regarding "true" causal structure

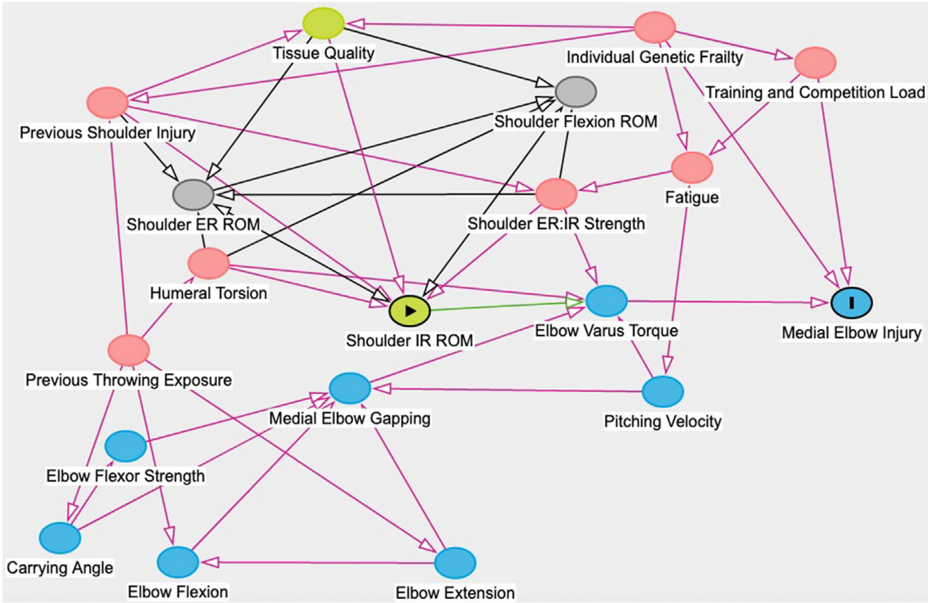

Fig 2. Suggested initial directed acyclic graph (DAG). This complex DAG is our suggestion on the causal structure between preseason shoulder internal range of motion (ROM) and medial elbow injury in professional baseball pitchers within the first 3 months of data collection (i.e., spring training and the first month of the season). It should be noted that, in accordance with Pearl,[31] the "tissue overload" node has been hidden as the causal pathway—in agreement with the model of Windt and Gabbett[59]—and this node is transitive to medial elbow injury in relation to all other factors. As reported by Hernán and Robins,[32] a DAG only needs to represent the minimal nodes to reflect structural confounding to block all backdoor paths. Pitching biomechanical nodes are not reported because they do not relate to backdoor paths within this DAG. (ER, external rotation; IR, internal rotation.)

Because RCTs are not a true option to answer this important question, one must rely on prospective observational studies (Table 2). It should be noted that using this methodology does not imply that these questions are unanswerable or that these potential conclusions should have less weight in their scientific foundation. If prospective observational studies are carefully designed,[47] with adequate (large) sample sizes, causal questions can be answered with robust scientific rigor.[48] These studies must require careful controlling of confounders[30] and other biases (e.g., data missingness,[49] misclassification,[50] immortal time,[51] and measurement error[52]) to truly investigate the potential for a causal relation. To account for the multitude of confounders and biases, researchers need to develop "scientific models before statistical models."[53] In other words, one must design a plausible causal model and identify methods to control for appropriate confounders and biases before proceeding with data collection or statistical analyses.[53] This "scientific model" should ideally be constructed through an appropriate causal DAG.[32,54] The reason behind this scientific methodology is that statistical analyses alone cannot decipher causal relations.[30,53] Although beyond the scope of this article, arbitrarily controlling for different variables (e.g., stepwise regression[55]) can bias the results by either artificially inflating,[56] decreasing,[57] or completely nullifying[58] the true causal (or non-causal) relation. Furthermore, the inclusion of "all measured factors" or a set of attainable factors does not assess causal relations but assesses only associations.[32,54] To navigate these statistical biases, one must use prior scientific, clinical, and biological knowledge to construct the DAG.[32,54] Different hypotheses can then be systematically tested to decipher the causal structure, and the causal structure can be refined over time.

Modifiable Factors in Future Studies of Shoulder ROM

So, where does baseball elbow injury research go from here? First, we must clearly define the purpose of future baseball injury studies. Are associations, prediction, or causality being investigated? As seen within this article, these are different scientific constructs (all valid and important aims) with different scientific methodologies and clinical implications.[25] If one is trying to understand causality, one must start with the specific causal question that is defined through a causal DAG. Although beyond the scope of this article, it should be highlighted that not all factors may be collected and included in a DAG and that DAGs change for each specific causal question.[32,33,53,54]

Owing to the intricacies in designing causal structures, we propose a DAG as a scientific model to assess the causal effect of preseason shoulder internal rotation ROM on medial elbow injuries in professional baseball players in the first 3 months of baseball spring training and the season (Fig 2). The reader will notice that the causal model is extremely specific as subtle changes in the scientific question can have ramifications on the causal structure. We chose this specific causal model because static models are less intricate compared with temporal dynamic models (also known as "time-varying confounding").[60] Furthermore, shoulder internal rotation ROM was chosen because this is the most assessed prognostic factor identified in relation to baseball elbow injuries.[24] The period of the first 3 months after measurement is clearly defined because shoulder ROM may change throughout the season,[61] causing a degradation in the relation between initial preseason shoulder ROM measurements and middle- or late-season arm injuries.[62] We would like to highlight that this proposed causal DAG is not the final model: We invite others to comment on and improve this DAG. Cumulatively, this effort will advance our understanding of the potential causal systems between shoulder ROM and baseball elbow injuries.

Although a full discussion of the presented DAG is beyond the scope of this article, it is pertinent to orient the reader to the main DAG highlights. This causal DAG has been created for an ideal scenario, with all factors observable and collected. The proposed causal factor, shoulder internal rotation, has a direct effect on medial elbow injuries, with a secondary pathway to elbow varus torque to medial elbow injury. There are multiple strategies for factor conditioning to block all confounding (i.e., close all backdoor paths).[30,39] To evaluate the total causal effect, the potential conditioning scenarios are as follows:

- Humeral torsion, individual genetic frailty, previous shoulder injury, shoulder external rotation—internal rotation strength
- Humeral torsion, previous shoulder injury, shoulder external rotation—internal rotation strength, tissue quality

To evaluate only the direct effect, the potential conditioning scenarios are as follows:

- Elbow varus torque, fatigue, individual genetic frailty, pitching velocity
- Elbow varus torque, individual genetic frailty, pitching velocity, previous shoulder injury, shoulder external rotation—internal rotation strength
- Elbow varus torque, individual genetic frailty, training and competition load

We would like to draw the reader's attention to shoulder external rotation and shoulder flexion ROM. Within this DAG, these should not be conditioned on (i.e. controlled for) because they induce what is termed "collider bias."[56] This occurs when multiple arrows are "pointed" to a node with other paths closed. Collider bias opens up further confounding and actually biases the causal effect.[56,57]

Conclusions

Until we clearly define what the scientific question is (association, causal, or prediction), there will continue to be confusion on the potential prognostic and causal relations between shoulder ROM and arm injuries in baseball players. Although RCTs are the gold standard in causal research, these methodologic designs may not be feasible or ethical in the sports setting. Prospective observational studies are required, with careful controlling of confounding and biases to discern true causal relations. Scientific models need to be clearly and precisely defined prior to data collection and statistical analyses because data and analyses alone cannot decipher causal relations. To jump-start this process, we have proposed a causal DAG for shoulder internal rotation ROM as a cause-effect relation to medial elbow injuries in professional baseball pitchers. The details of portions of this model can be validated with piecemeal observational studies, which will provide weights between individual nodes. We invite other experts, through open commentary, to help improve this DAG. Although some readers may believe that this discussion is merely scientific semantics, these issues, until clearly defined and executed, will continue to inhibit clinical examinations and impact throwing-arm health.

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