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FlexPro Grip White Paper

The Strength–Velocity Gap in Driveline Athletes: A Capacity-Based Framework for Understanding UCL Injury Risk in Pitchers

Abstract
This analysis evaluates assessment data from Driveline athletes tested with FlexPro Grip's Rapid Flexion Test to examine how forearm flexor capacity relates to peak pitch velocity, and how that relationship may inform UCL injury risk, fatigue sensitivity, and force production capacity. The dataset was filtered to include athletes who recorded peak velocities of at least 80 mph and produced a minimum of 100 units of force in both fingertip and midfinger rapid flexion tests. After filtering, 532 athletes remained for analysis.

Recent work has increasingly challenged the assumption that elbow valgus torque alone can function as a reliable prospective injury predictor. Although valgus torque remains biomechanically relevant, it is tightly coupled with velocity, affected by range restriction, and limited by modeling assumptions that cannot determine how load is distributed among the UCL, joint capsule, and flexor-pronator mass [3]. This is precisely why a capacity-based framework is needed. Rather than asking only how much torque a pitcher generates, the more actionable question is whether the athlete has sufficient forearm flexor capacity to help manage the demands created by his velocity.

The findings of this analysis show that 28% of athletes tested at or above their velocity-based strength target, 27% tested within 1-5 mph, 24% tested within 6-10 mph, 13% tested within 11-15 mph, and 8% tested more than 15 mph below peak velocity. These results suggest that while slightly more than half of the population was operating near expected capacity, a substantial percentage demonstrated meaningful strength-velocity gaps. When interpreted alongside evidence that the medial elbow musculature contributes to stress shielding of the UCL, and that reduced finger flexor strength and imbalance are associated with medial elbow injury, these data support the use of objective forearm testing as part of a broader, integrated model of throwing risk [1,2].

Introduction
Driveline Baseball is widely considered the premier baseball training facility in the world, combining cutting-edge biomechanics, data-driven player development, and a proven track record of producing elite performance gains and professional-level talent. Through the integration of motion capture, force plate analysis, individualized programming, and relentless innovation, Driveline has become the gold standard for understanding and developing high-level throwers.

This analysis evaluates assessment data from Driveline athletes tested over the past 12 months using FlexPro Grip's Rapid Flexion Test. The dataset was filtered to include athletes who (1) recorded peak velocities of at least 80 mph in Driveline throwing sessions and (2) produced a minimum of 100 units of force in both fingertip and midfinger rapid flexion tests. After filtering, 532 athletes remained for analysis. The objective was to examine how forearm flexor strength relates to each athlete's peak velocity.

Recent advances in biomechanical and neuromuscular assessment have shifted attention toward the role of the forearm flexor-pronator mass as a primary contributor to medial elbow stability. While traditional models emphasized passive structures such as the ulnar collateral ligament (UCL), emerging evidence demonstrates that dynamic stabilizers, particularly the flexor digitorum superficialis (FDS) and flexor digitorum profundus (FDP), play a critical role in mitigating valgus stress during high-velocity throwing [1,2].

A retrospective cohort study by Brolinson et al. demonstrated a statistically significant relationship between reduced finger flexion strength, altered midfinger-to-fingertip ratios, and medial elbow injury in pitchers [1]. Complementing this, Yanai et al. showed that the medial elbow musculature generates varus force that helps shield the UCL from excessive valgus stress [2]. Together, these findings shift the injury model away from ligament-centric thinking and toward the musculature's capacity to generate force quickly and repeatedly under fatigue.

FlexPro Grip enables this analysis by isolating and quantifying the strength of the finger flexors responsible for dynamic stabilization of the medial elbow. This data is increasingly being used across professional and collegiate baseball to identify strength deficits, monitor fatigue, and guide targeted interventions.

This paper also incorporates the implications of recent editorial commentary by Giordano and Oliver, which argues that elbow valgus torque is poorly suited as a standalone injury predictor [3]. Their central point is not that torque is irrelevant. Rather, torque is an incomplete and noisy proxy when used in isolation because it does not tell us how the elbow manages or distributes that load. That distinction is central to the argument advanced here: UCL risk is not simply a function of how much load is present, but whether the biological system responsible for managing that load has sufficient capacity.

Why Torque Alone Is an Incomplete Injury Model

Elbow valgus torque is often treated as a surrogate for UCL injury risk because it appears to represent the external demand placed on the medial elbow during pitching. This makes intuitive sense: as velocity increases, elbow load increases, and the magnitude of valgus torque approaches levels known to place substantial stress on the UCL [4]. And at some point excessive load can exceed the capacity of the ligament and surrounding tissues. However, a metric can be biomechanically relevant and still be limited as a prospective injury predictor.

Giordano and Oliver identify several reasons why valgus torque is limited when used as a standalone marker. First, torque is tightly linked to fastball velocity. Multiple studies have demonstrated that increases in pitch velocity are accompanied by increases in elbow varus/valgus torque, although the strength and consistency of this relationship vary depending on study design and population [9–12]. Across wide ranges of athletes, harder throwers generate more torque. Within a narrower population, such as high-level pitchers throwing within a relatively small velocity band, the relationship becomes noisier and less predictive [3]. In practical terms, if two pitchers both throw 92-95 mph, a single torque number may not meaningfully distinguish which athlete is better prepared to tolerate that load. Prospective work has also demonstrated that elbow valgus torque does not independently predict medial elbow injury when controlling for workload and age, further reinforcing the limitations of torque as a standalone risk metric [7].

Second, torque estimates depend on modeling assumptions. Inverse dynamics requires assumptions about limb mass, joint centers, segment geometry, and how the elbow is represented mechanically. Most models simplify the elbow as a hinge and rely on generalized anthropometric assumptions [3]. These assumptions may be acceptable for estimating group-level biomechanics, but they are less reliable when attempting to stratify injury risk for a single pitcher.

Third, and most important for this analysis, motion capture cannot determine how load is distributed internally. The same measured valgus torque may be experienced differently depending on the capacity and timing of the flexor-pronator mass, the integrity of the UCL, the stiffness of the muscle-tendon unit, local fatigue, tissue quality, prior injury history, and workload exposure. Torque describes external demand. It does not measure how that demand is distributed or tolerated within the biological system.

This limitation does not diminish the importance of biomechanics. Instead, it clarifies what biomechanics must be paired with. A high-velocity pitcher should not be evaluated only by the load he creates. He should also be evaluated by whether the structures responsible for controlling, distributing, and absorbing that load are physically prepared to do so.

Rationale for a Capacity-Based Model

The strength-velocity gap is based on a simple premise: as velocity rises, the demand placed on the medial elbow rises, and the muscular system responsible for dynamic stabilization must scale accordingly. A pitcher who throws 95 mph with the forearm flexor capacity typically seen in an 87 mph thrower is not simply “weak.” He is operating with a mismatch between output and support capacity.

This is materially different from evaluating absolute strength alone. A 170-unit Rapid Flexion Test may be adequate for one pitcher and inadequate for another depending on velocity. Capacity must be interpreted relative to demand. The relevant question is not whether the athlete is strong compared with the general population, but whether he is strong enough for the stress created by his own throwing profile.

This framework also aligns with the editorial critique of torque-only models. If torque and velocity are difficult to separate, then velocity should not be ignored. It should be used as the anchor for interpreting whether the stabilizing system is adequately developed. In other words, rather than trying to remove velocity from the equation, the strength-velocity gap accepts velocity as a central demand variable and evaluates whether the athlete's forearm flexor capacity is proportionate to that demand.

Methods

Rapid Flexion Test data was analyzed from 532 athletes across a 12-month period. Trials in which athletes produced less than 100 units of force in either fingertip or midfinger testing were excluded to minimize the impact of submaximal effort or measurement error. All athlete data included in this analysis were fully de-identified prior to evaluation. No personally identifiable information was accessed or used at any stage of the analysis, and all results are reported in aggregate form to ensure individual anonymity.

Force values are reported in standardized proprietary units derived from device output and are used for internal comparison across athletes rather than as absolute force measurements.

Each athlete's fingertip and midfinger force outputs were compared to expected velocity-based strength benchmarks derived from FlexPro Grip's internal database. The velocity used for this comparison was each athlete's peak pitch velocity recorded during his Driveline assessment.

These FlexPro Grip benchmarks are based on the 80th percentile of force at each velocity within a dataset of approximately 3,000 athletes and represent the level of forearm flexor capacity we believe is required to generate sufficient varus torque to protect the UCL during high-velocity throwing.

Athletes were then categorized based on the difference between their strength and their actual peak velocity. This difference is referred to as the strength-velocity gap. The purpose of this categorization was to determine whether each athlete's forearm capacity appeared sufficient to support his throwing demands.

This analysis should be interpreted as a practical performance and risk-stratification framework, not as a definitive prospective injury model. While the framework is grounded in established biomechanical and physiological principles, the current analysis does not establish causation and should be interpreted as identifying capacity-demand mismatches rather than directly predicting injury outcomes.

The data identify mismatches between velocity and measurable forearm capacity. Future prospective work is needed to determine how strongly these categories predict UCL injury, flexor-pronator symptoms, reductions in throwing availability, or measurable fatigue responses over a season.

Results

Among the 532 athletes included in this analysis, the distribution across strength-to-velocity categories was as follows:

Strength-Velocity Category	Percent of Athletes	Athlete Count	Interpretive Meaning
At or above peak velocity	28%	148	Forearm capacity meets or exceeds velocity demand
Within 1-5 mph	27%	144	Near adequate capacity; modest improvement may increase margin of safety
Within 6-10 mph	24%	128	Clear mismatch between demand and capacity
Within 11-15 mph	13%	69	Large deficit; reduced margin for error
More than 15 mph below peak velocity	8%	43	Severe mismatch; highest concern for capacity-demand imbalance

While over half of all athletes (55%) tested within 5 mph of their peak velocity, a substantial portion demonstrated meaningful deficits in forearm flexor capacity relative to their velocity demands.

Specifically, 45% of athletes tested 6 mph or more below their velocity-based target, and 21% tested 11 mph or more below their target. These are not trivial differences if one accepts that velocity increases medial elbow demand and that the flexor-pronator mass contributes to shielding the UCL.

Interpretation of Findings

Pitch velocity has been shown to be positively associated with elbow valgus torque, particularly within pitchers, although the strength of this relationship varies depending on population and methodology [9-12]. As velocity increases, so does the demand placed on the dynamic stabilizers of the medial elbow. When muscular capacity does not scale accordingly, excess load is more likely to be transferred to passive structures, including the UCL.

The difference between peak velocity and FlexPro Grip's strength targets can be interpreted as a strength-velocity gap. This gap provides a practical framework for evaluating whether an athlete's musculature appears sufficient to support his throwing demands. The framework is not intended to claim that strength alone predicts injury. Rather, it identifies a measurable and modifiable component of the system that determines how the elbow tolerates load.

Athletes who tested either above or within 1-5 mph of their peak velocity, representing 55% of the population, are generally operating near adequate capacity. Those within 1-5 mph are not necessarily deficient, but they are positioned such that relatively small strength gains may meaningfully improve their margin of safety.

Athletes in the 6-10 mph range, representing 24% of the population, demonstrate a clear mismatch between demand and capacity. These athletes are more likely to rely on passive structures, such as the UCL, particularly when fatigued. This category may be especially important from a player development standpoint because the gap is large enough to matter but likely small enough to be trainable over a realistic time frame.

Those in the 11-15 mph and greater than 15 mph categories, representing 13% and 8% respectively, show progressively larger deficits. In these athletes, muscular capacity is increasingly insufficient relative to throwing demands, and the margin of safety at the elbow is reduced. The more severe the mismatch, the more important it becomes to evaluate not only strength, but also rate of force development, fatigue resistance, soreness history, prior UCL or flexor-pronator symptoms, throwing volume, and recovery patterns.

The commentary by Giordano and Oliver exposes the central weakness of torque-only thinking. If torque is inseparable from velocity across meaningful performance ranges, and if single-session torque measurements are too noisy to reliably identify risk in an individual pitcher, then the next logical step is not to abandon load monitoring. It is to pair load with capacity [3].

This distinction is critical. A pitcher does not tear his UCL because a motion capture report labels his torque as high. Tissue fails when the stress applied to that tissue exceeds the tissue's capacity to tolerate it, and that capacity is influenced by muscle strength, timing, fatigue, tendon stiffness, prior injury, and cumulative workload. Valgus torque is part of the demand side of the equation. Forearm flexor capacity is part of the supply side.

Motion capture cannot tell us how much load is borne by the ligament versus the surrounding musculature, and modeling studies suggest that load sharing between muscle, ligament, and joint structures is highly variable and dependent on individual neuromuscular and anatomical factors [3,5]. This is the exact blind spot that objective forearm testing begins to address. If two pitchers generate similar torque at similar velocities, but one has substantially greater finger flexor capacity and better fatigue resistance, their internal elbow environments may be very different. A torque-only model may treat them similarly. A capacity-based model would not.

This does not mean the Rapid Flexion Test replaces biomechanics. The stronger position is that it complements biomechanics by measuring a physiological variable that motion capture cannot directly quantify. Biomechanics describes how much demand is being created. FlexPro Grip helps evaluate whether the athlete has the local muscular capacity to help manage that demand.

Mechanistic Basis: Why the Flexor-Pronator Mass Matters

The protective role of the flexor-pronator mass is highly dependent on force production, rate of force development, and fatigue resistance. Yanai et al. demonstrated that the medial elbow musculature contributes varus force that helps shield the UCL from valgus stress [2].

Additional biomechanical work has demonstrated that the medial elbow musculature is capable of generating meaningful varus force under valgus loading conditions, further supporting its role in dynamic stabilization [2,8]. This provides a direct biomechanical rationale for evaluating the strength of the muscles that contribute to dynamic medial elbow stability.

The FDS and FDP are particularly relevant because of their anatomical relationship to the medial elbow and their role in finger flexion. Their ability to generate force rapidly may help contribute to medial elbow compression and varus support during the late cocking and early acceleration phases, when valgus stress rises rapidly. If these muscles are underdeveloped or fatigued, their ability to help unload the UCL may be reduced.

Brolinson et al. provide additional support for this model by demonstrating an association between reduced finger flexion strength, altered midfinger-to-fingertip ratios, and UCL injury risk [1]. The importance of this finding is not merely that weak athletes may be at greater risk. It is that deficits in very specific finger flexion patterns may reflect impaired capacity of the dynamic stabilizing system most relevant to the medial elbow.

Together, these findings support a shift in thinking. The UCL should not be viewed as the only structure resisting valgus load. It should be viewed as one component of a broader system. When the flexor-pronator mass is strong, fast, and fatigue-resistant, more load can be managed dynamically. When it is weak, slow, or fatigued, more stress may be transferred to passive structures.

Fatigue and Mechanistic Implications

The protective role of the flexor-pronator mass is highly dependent on both force production and fatigue resistance. When fatigued or underdeveloped, this protective effect diminishes. In athletes with a strength-velocity gap of 6 mph or greater, fatigue becomes a critical risk amplifier. This interaction is further influenced by cumulative workload, as repeated exposure to high-intent throwing without sufficient recovery may progressively reduce functional capacity and increase reliance on passive structures. Under fatigued conditions, the muscular contribution to dynamic elbow stability decreases. This can lead to increased reliance on the UCL, greater joint gapping, and elevated ligament strain.

This can be understood mechanistically. Peak valgus stress during pitching occurs rapidly near maximal external rotation of the throwing arm, requiring fast and coordinated muscular activation of the flexor-pronator mass. If the flexor-pronator mass cannot generate sufficient force quickly enough, load shifts toward the UCL, joint stability decreases, microtrauma may accumulate, and injury risk may increase.

These effects are further exacerbated by fatigue, which reduces muscle-tendon unit stiffness and force production capacity. Rate of force development is especially important because it captures not only whether the athlete can generate force, but whether he can generate it quickly enough to matter during pitching. General strength may still be relevant, but in a movement where key loading windows occur over extremely short time scales, timing and rapid force expression are central. Early rate of force development has been shown to be particularly sensitive to neuromuscular fatigue and may decline before peak force, making it a potentially more sensitive indicator of functional capacity in high-speed movements such as pitching [6].

This is why the strength-velocity gap should be viewed as a baseline capacity measure, not the entire risk model. A pitcher who is 8 mph below his target when fresh may be substantially farther below the functional requirement after a high-volume outing, during a condensed throwing week, or late in a season. Conversely, an athlete who begins the season at or above target may have a larger buffer against fatigue-related decline.

Limitations: Absence of Rate of Force Development

This analysis evaluates peak force but does not account for the rate at which force is produced. This is a key limitation.

Pitching occurs over very short time scales, and the ability to generate force rapidly may be as important as peak force itself. An athlete may demonstrate adequate strength but still be unable to apply that force quickly enough during the throwing motion. For this reason, peak force should be considered a foundational measure, while rate of force development may provide additional sensitivity to fatigue, readiness, and throwing-specific stabilization capacity.

Future analysis incorporating rate of force development may provide a more sensitive measure of fatigue, readiness, and injury risk. This is particularly important because early RFD may decline before peak force and may better reflect neuromuscular fatigue in short time windows. [6] If the flexor-pronator mass must contribute to stabilization during the rapid rise in valgus stress, then early force production may be one of the most important missing variables in current injury models.

Integrated Conceptual Model

A torque-centered model tends to simplify pitching injury risk into the following sequence:

- Higher velocity produces higher torque.
- Higher torque increases UCL stress.
- Higher UCL stress increases injury risk.

This model is not wrong, but it is incomplete. It does not explain why two pitchers with similar velocity and similar measured torque can have different injury outcomes. It also does not explain why some athletes tolerate years of high velocity while others break down quickly.

A more complete model is:

- Velocity creates demand.
- Demand increases valgus torque and medial elbow stress.
- The flexor-pronator mass contributes to dynamic stabilization and stress shielding.
- Strength, rate of force development, fatigue resistance, and tissue quality determine how much load is managed dynamically.
- When demand exceeds capacity, more stress is transferred to passive structures, including the UCL.
- Repeated exposure under insufficient capacity increases the likelihood of tissue breakdown.

This integrated model better reflects the multifactorial nature of throwing injury. It preserves the relevance of torque while recognizing that torque is not destiny. The decisive variable is not load alone, but the relationship between load and capacity. This framework helps explain why pitchers with similar velocity and similar measured torque can demonstrate markedly different injury outcomes, as the determining factor is not load alone, but the capacity of the system responsible for managing that load.

Implications for Player Development

These findings suggest that forearm flexor strength should be evaluated and developed alongside traditional performance indicators such as velocity, workload, and biomechanics.

The strength-velocity gap provides a practical method of identifying athletes whose physical capacity may not align with their throwing demands. Athletes within 0-5 mph of their peak velocity may require only modest improvements to optimize both performance and durability. In contrast, athletes beyond this range require targeted strength development to reduce reliance on passive structures.

From a workload management standpoint, athletes with deficits of 6 mph or greater should place increased emphasis on avoiding throwing in a fatigued state, as their reduced muscular capacity limits their ability to protect the UCL under stress. These athletes may require more careful monitoring during velocity development, bullpen ramp-ups, return-to-throw progressions, high-intent throwing blocks, and congested competitive schedules.

Integrating objective forearm strength testing such as FlexPro Grip's Rapid Flexion Test into a monitoring routine enables earlier identification of risk, more individual-specific programming, and more informed return-to-throw and in-season decision-making.

Because forearm flexor capacity is both measurable and trainable with FlexPro Grip, this framework provides a practical opportunity not only to identify risk, but to intervene in a targeted manner that may improve both performance and durability.

Practical Applications

The value of the strength-velocity gap is that it converts an abstract injury concept into an actionable programming variable. Rather than simply telling an athlete that his elbow torque is high, the program can identify whether his forearm flexor capacity is proportionate to his velocity and then prescribe targeted work to close the gap.

Potential applications include:

- Pre-season screening to identify athletes below velocity-based capacity targets.
- In-season monitoring to detect loss of capacity that may reflect accumulated fatigue.
- Return-to-throw decision-making to ensure forearm capacity is restored as velocity increases.
- Velocity development programs to confirm that local stabilizing capacity scales with performance gains.
- Rehabilitation progressions after UCL, flexor-pronator, or medial elbow symptoms.
- Individualized workload decisions when athletes show large strength-velocity deficits or rapid declines from baseline.

This approach does not require programs to abandon existing biomechanics, strength and conditioning, or throwing models. It adds a missing local capacity measure to an already data-rich environment. That is especially important for organizations that already collect velocity, pitch count, workload, force plate, and motion capture data but lack a direct assessment of the medial elbow's dynamic stabilizers.

Interpreting Strength-Velocity Categories

At or above velocity target: These athletes appear to have forearm flexor capacity that meets or exceeds the expected requirement for their velocity. This does not mean they are risk-free, but it suggests that forearm capacity is not an obvious limiting factor at the time of testing.

Within 1-5 mph: These athletes are near expected capacity. They may benefit from modest targeted training, especially if they are entering a velocity development block, returning from time off, or showing signs of fatigue. This category should be interpreted as a small margin rather than a major deficit.

Within 6-10 mph: This is the first category that should raise meaningful concern. These athletes appear to be throwing at velocities that exceed their measured forearm capacity. They may require focused strength development, fatigue monitoring, and greater caution during high-intent throwing.

Within 11-15 mph: These athletes show a large mismatch between performance and support capacity. From a practical standpoint, they may need a more deliberate intervention plan and should be monitored carefully during high-volume or high-intent periods.

More than 15 mph below velocity target: These athletes demonstrate the largest mismatch. While the data do not prove that they will sustain an injury, they are likely operating with diminished dynamic medial elbow stability relative to their throwing demands. This group should be prioritized for additional evaluation and targeted programming.

Future Research Directions

The next step is prospective validation. The strength-velocity gap should be evaluated longitudinally to determine whether larger deficits predict UCL injury, flexor-pronator symptoms, time-loss elbow injuries, reductions in availability, or acute post-throwing fatigue responses.

Future work should also incorporate rate of force development. A combined model that includes peak force, early RFD, late RFD, fatigue response, and velocity may be substantially more informative than peak force alone. This is particularly relevant because a pitcher may possess adequate maximum force but lack the ability to access that force during the short stabilization window required in throwing.

Finally, these measures should be integrated with workload, biomechanics, and physiology rather than chasing single-session proxies. FlexPro Grip testing provides a physiological component that can be layered onto existing throwing data to create a more complete risk profile.

Limitations of the Current Analysis

Several limitations should be acknowledged. First, this analysis is cross-sectional and does not include prospective injury outcomes. As a result, the strength-velocity gap should be interpreted as a capacity-demand mismatch, not as a proven injury prediction threshold.

Second, the velocity-based benchmarks are derived from FlexPro Grip's internal database and should continue to be refined as the dataset grows. The use of the 80th percentile provides a practical target, but future work may determine that different thresholds are more appropriate for different ages, levels, roles, injury histories, or throwing profiles.

Third, the current analysis focuses on fingertip and midfinger rapid flexion strength and does not include ulnar deviation, pronation, endurance, or direct rate-of-force-development measures. Because medial elbow stability is multifactorial, no single test should be treated as comprehensive.

Fourth, this analysis does not claim that forearm flexor weakness is the sole cause of UCL injury. UCL injury risk is influenced by workload, velocity, mechanics, tissue quality, prior injury, fatigue, recovery, training history, and biological variability. The argument is narrower and more defensible: forearm flexor capacity is a measurable, modifiable factor that likely influences how the medial elbow manages throwing stress.

Conclusion

The integration of FlexPro Grip's finger flexion strength testing alongside performance metrics provides a practical framework for evaluating UCL injury risk.

Consistent with prior research demonstrating the role of forearm flexor strength in medial elbow stability, these findings suggest that the mismatch between strength and velocity may be a key determinant of risk. Athletes who throw at velocities that exceed the capacity of their musculature are likely operating with diminished dynamic medial elbow stability and greater reliance on the UCL.

This risk is further amplified under fatigue, particularly in athletes with measurable strength deficits. The recent critique of torque-only models reinforces this conclusion. Torque remains relevant, but it is incomplete. It describes demand without measuring capacity, and it cannot determine how load is distributed across the ligament and the surrounding musculature. [3]

The strength-velocity gap offers a more actionable framework because it evaluates whether the athlete's local stabilizing system is physically prepared for the velocity he is producing. For high-level baseball programs, this creates a pathway to identify deficits earlier, individualize training more precisely, and better align velocity development with tissue capacity.

Acknowledgement

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Conflict of Interest Disclosure

FlexPro Grip (FPG) is a commercial entity that develops and provides hardware and software used to assess and train forearm flexor capacity. Driveline Baseball is a paying customer of FlexPro Grip, and all FlexPro Grip devices and software utilized in this analysis were provided on a commercial basis. No equipment or services were provided free of charge. The authors acknowledge this financial relationship as a potential conflict of interest.

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