Technical Methodology Summary

SANTOS: Application to Injury Analysis and Expert Testimony

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1. OVERVIEW

Santos is a high-fidelity digital human simulation platform used to analyze human motion and quantify biomechanical forces during physically demanding activities and injury scenarios. The system integrates principles from biomechanics, rigid-body dynamics, and optimization-based motion prediction to estimate internal forces and kinematics consistent with physical laws and human physiological constraints. In the context of legal and expert witness applications, Santos is used to evaluate **injury causation** by quantifying forces, torques, and motion characteristics associated with specific case scenarios (e.g., falls, collisions, lifting events, and product interactions).

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2. MODELING FRAMEWORK

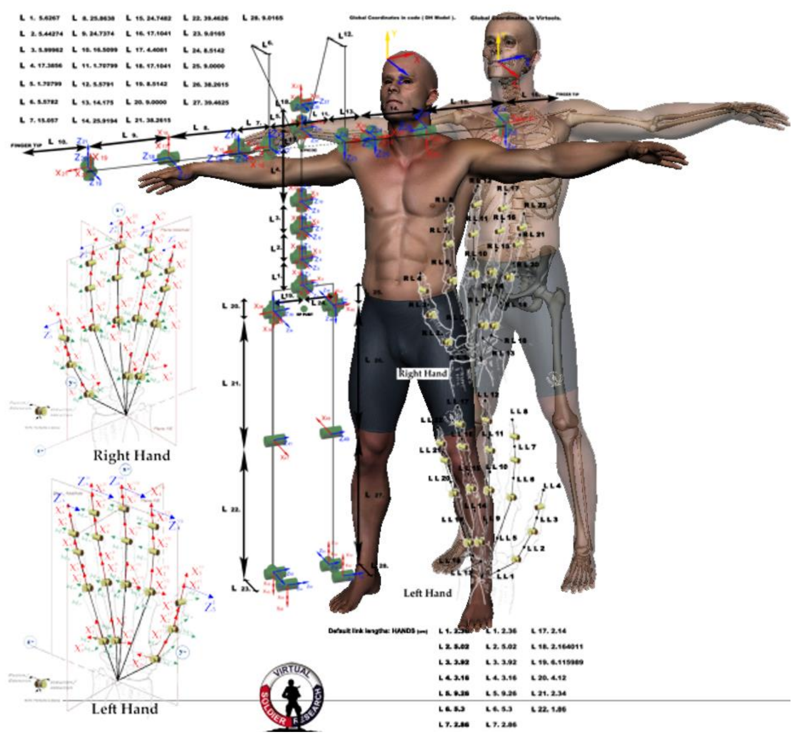
2.1 Digital Human Representation

Santos represents the human body as a linked system of rigid segments connected by joints. Each segment is defined by anthropometric parameters (e.g., mass, length, inertia), which can be scaled to match subject-specific characteristics.

Joint definitions incorporate anatomical constraints, including:

- Range of motion limits
- Degrees of freedom (e.g., hinge, ball-and-socket)
- Joint coupling where applicable

Muscle forces and joint torques are computed to satisfy motion requirements while maintaining physiological plausibility.



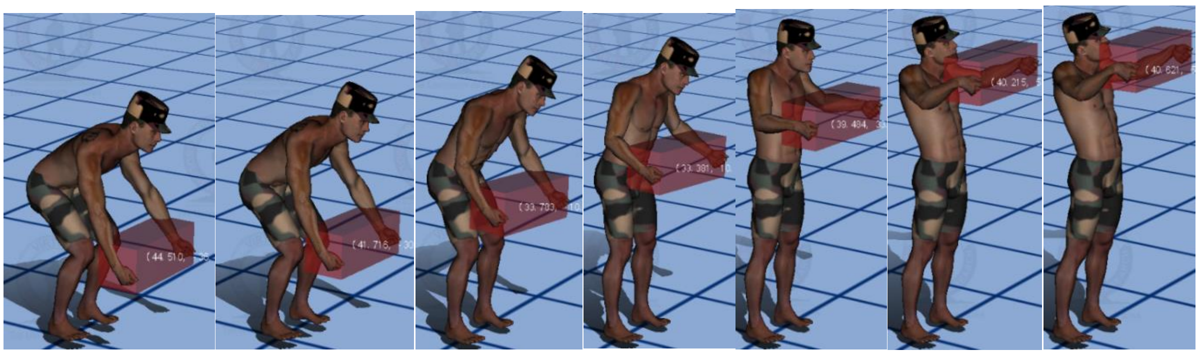
📌 **Figure:** Full-body digital human model showing segment definitions, joint structure, and degrees of freedom.

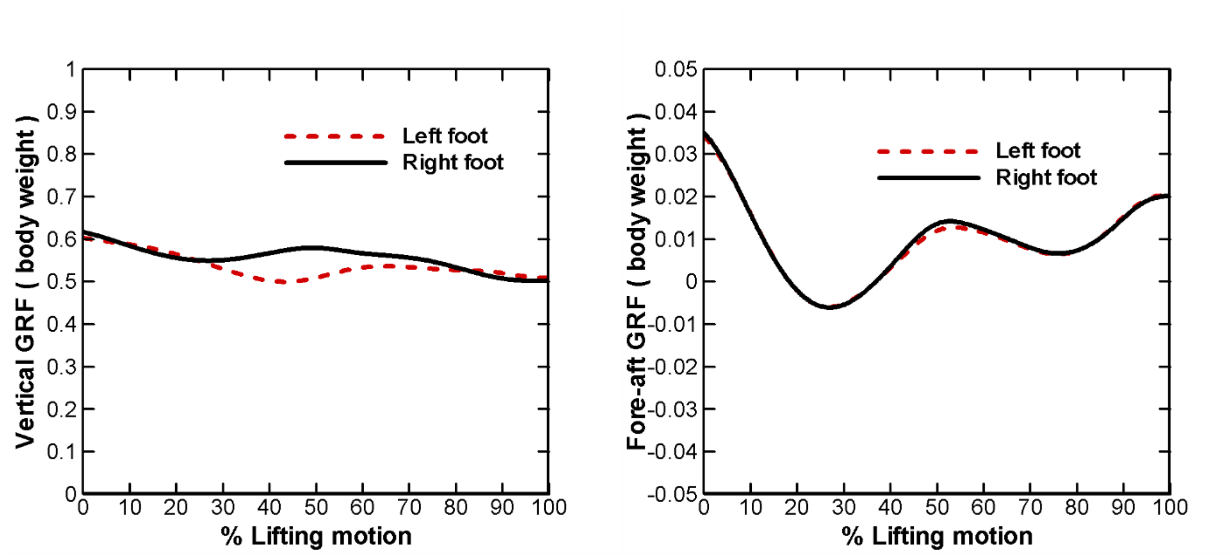
2.2 Equations of Motion

The system is governed by Newtonian mechanics. Motion is computed by solving the equations of motion for a multi-body system:

- Balance of forces and moments
- Gravity and external forces
- Contact interactions (e.g., ground reaction forces)

Dynamic consistency is maintained throughout the simulation.





(a) (b)

Figure 2. Ground reaction forces for dynamic box lifting using the weighted sum performance measure (a) vertical GRF, (b) fore-aft GRF

2.3 Motion Generation and Optimization

Human motion is generated or reconstructed using optimization-based methods. The system determines joint trajectories and forces that:

- Satisfy physical constraints (dynamics, contact)
- Respect anatomical limits
- Minimize physiologically relevant cost functions (e.g., effort, fatigue)

This approach enables:

- Reconstruction of observed motion
- Prediction of motion under specified conditions

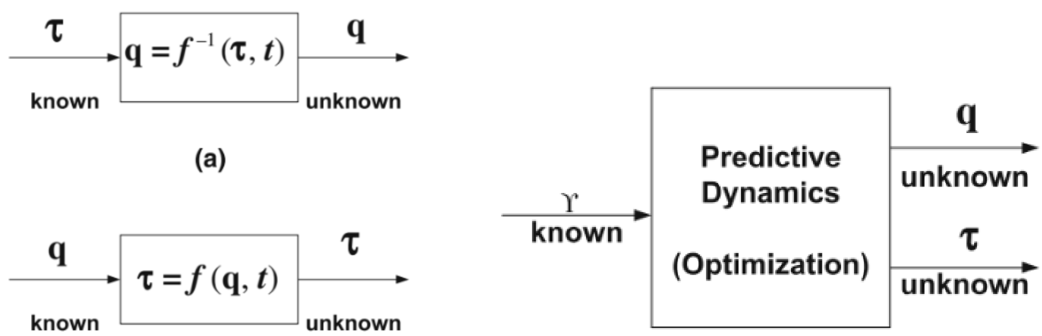


Figure 3: (a) typical forward and inverse dynamics (b) Predictive Dynamics yields motion profiles and torques profiles, i.e., predicts the dynamics of the motion.

Flow diagram showing optimization loop: inputs → constraints → solution → outputs.

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3. INPUTS AND SCENARIO DEFINITION

Simulations are constructed using case-specific inputs, which may include:

- Anthropometry (height, weight, segment proportions)
- Initial posture and body configuration
- Environmental conditions (surface, geometry, obstacles)
- External forces or events (impact, slip, load)
- Motion descriptions (if available from video or reports)

Inputs may be derived from:

- Case records
- Photographs or video
- Expert assumptions consistent with evidence

All assumptions are explicitly documented.

. **SANTOS INPUT PARAMETERS**

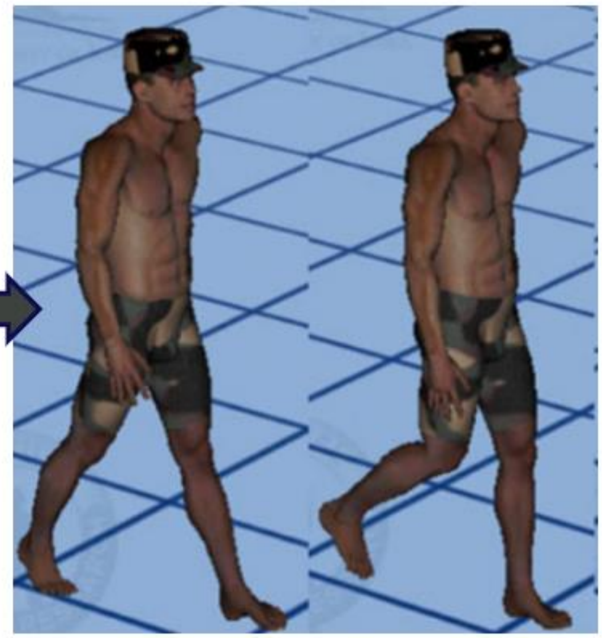
A. Anthropometry (Plaintiff Model)
- Height: **1.78 m (5'10")**
- Weight: **85 kg (187 lbs)**
- Age: **45 years**
- Strength: **Average (50th percentile male)**

B. Initial Motion Conditions
- Walking speed: **1.4 m/s** (normal walking)
- Step length: **0.75 m**
- Cadence: **~110 steps/min**

C. Slip Event Parameters
- Surface: wet tile floor
- Coefficient of friction (μ):
  - Dry: **0.6–0.7**
  - Wet: **0.2–0.3** (critical range)
- Slip initiation:
  - Heel contact phase
  - Horizontal velocity at heel: **~1.2 m/s**

D. Environmental Conditions
- Flat surface (0° incline)
- No hand support
- No external obstacles

4Injury threshold (literature):
~6,000 N (depending on posture)
👉 Interpretation:
- Severe slip → **injury-level loading plausible**



📌 **Figure 4** Example setup of a case scenario (e.g., slip and fall environment with initial posture).

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4. OUTPUTS AND QUANTITIES OF INTEREST

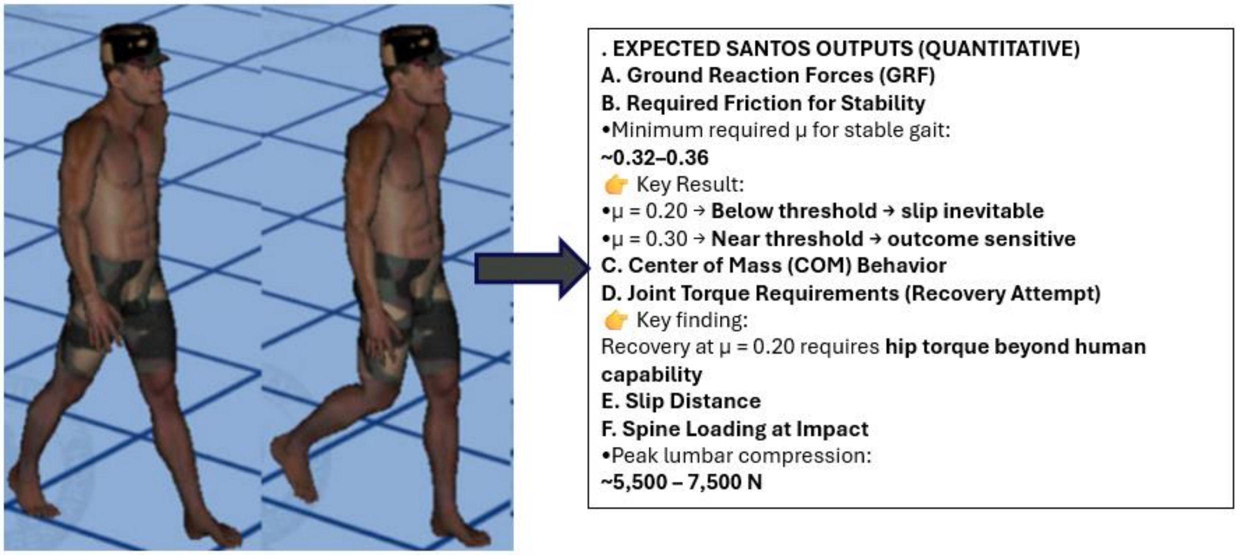
Santos produces quantitative outputs relevant to injury analysis, including:

4.1 Kinematics
- Joint angles and trajectories
- Body segment motion
- Velocity and acceleration

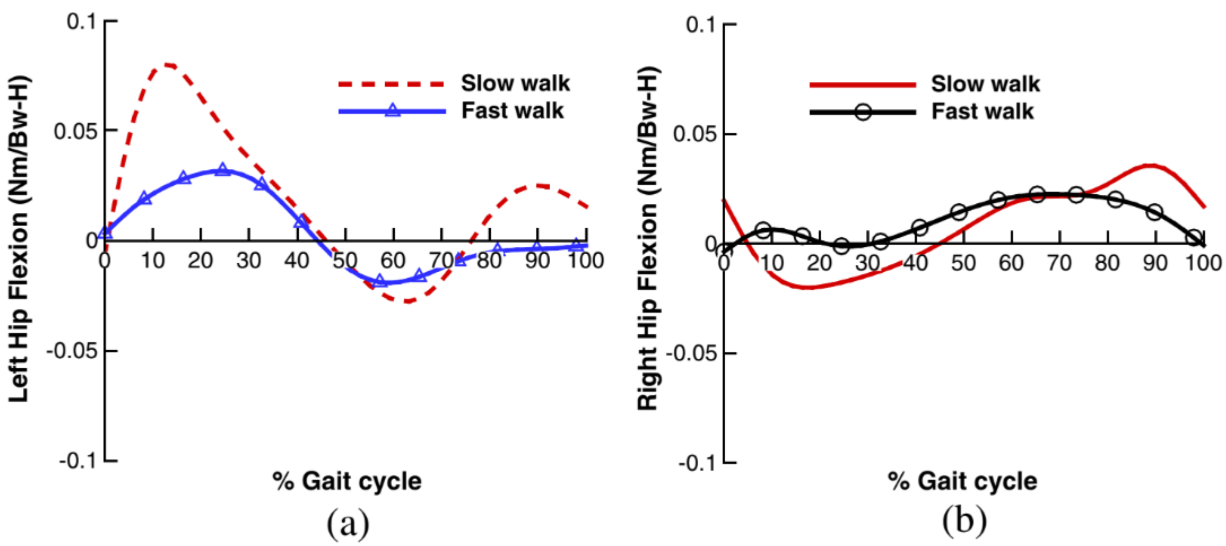
4.2 Kinetics
- Joint forces and torques
- Ground reaction forces
- Contact forces

4.3 Internal Loading Estimates
- Muscle forces
- Joint reaction forces
- Spine compression and shear loads

Outputs are provided as:
- Numerical data
- Graphs and time histories
- Visual animations and annotated frames



📌 **Figure 5 (recommended):**
Example plot of joint force or torque vs. time.



📌 **Figure 6 (recommended):**
Gait cycle: Joint torque profiles (a) left hip; (b) right hip;

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5. APPLICATION TO INJURY ANALYSIS
Santos is used to evaluate whether a given motion or event is consistent with reported injuries by:

1. Simulating the event based on available evidence
2. Quantifying biomechanical loads during critical phases
3. Comparing computed loads to established biomechanical thresholds and literature

4. Assessing plausibility of injury mechanisms

Example applications include:

- Slip and fall → spine loading
- Vehicle collision → cervical loading
- Lifting → lumbar compression
- Product interaction → joint stress

The system does not independently determine injury; rather, it provides **quantitative mechanical context** to support expert interpretation.

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6. ASSUMPTIONS AND LIMITATIONS

All simulations rely on assumptions that are explicitly stated and may include:

- Estimated body posture or motion
- Simplified contact conditions
- Idealized environmental representations

Limitations include:

- Dependence on input accuracy
- Variability in human physiological response
- Simplifications inherent in musculoskeletal modeling

Sensitivity analyses can be performed to evaluate the impact of key assumptions.

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7. VALIDATION AND SCIENTIFIC BASIS

Santos is grounded in established scientific principles, including:

- Newtonian mechanics
- Rigid-body dynamics
- Musculoskeletal modeling
- Optimization-based motion prediction

The methodology is consistent with approaches described in peer-reviewed biomechanics literature. Validation efforts include comparison to:

- Experimental motion capture data
- Known biomechanical benchmarks
- Published research findings

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8. USE IN EXPERT TESTIMONY

In legal applications, Santos is used as a **supporting analytical tool** to:

- Quantify forces underlying injury scenarios
- Provide visual and numerical evidence
- Enhance clarity of expert opinions

Results are presented alongside:

- Clearly stated assumptions
- Methodological transparency
- Interpretation by the expert witness

The tool supports, but does not replace, expert judgment.

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9. SUMMARY

Santos provides a physics-based framework for analyzing human motion and quantifying biomechanical forces in injury-related scenarios. By combining validated modeling techniques with case-specific inputs, the system enables expert witnesses to support their opinions with measurable, reproducible analysis.

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