Forward and Inverse Dynamics Reconstruction of a Staged Rugby Tackle

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I. INTRODUCTION

Sports participation is crucial to population health, but injuries carry short and long-term health consequences. In elite schoolboy rugby, injury incidence is 77/1000 match hours with concussions at 20/1000 hours [1], while in adult competitions the injured player proportion per year is around 50%, with tackles being the main injury cause [2]. However, little is known about contact forces/body kinematics leading to injuries in sporting collisions. Wearable sensors are promising, but challenges remain. Physics-based models with force predictions are subject to validation challenges [3-4]. We previously reported on staged rugby tackles recorded using a motion capture system [5]. Simulating these tackles using MADYMO (Helmond, The Netherlands) forward dynamics modelling highlighted challenges with the absence of muscle activation in the MADYMO pedestrian model [3]. Here our aim is to test whether combined inverse and forward dynamics modelling of a staged rugby tackle can yield a realistic estimate of tackle contact force.

II. METHODS

A combined forward and inverse dynamics approach was taken to estimate tackle contact forces without a direct load sensor, as impact force is challenging to measure in sporting collisions. To test this integrated approach, a staged tackle from [5] was chosen for forward and inverse dynamics model reconstruction.

For forward dynamics, the MADYMO pedestrian model applied by [4] was used, with pelvis initial position, orientation and velocity and the principal joint DOFs and their time derivatives extracted from the Vicon motion capture data using the Plug-in-Gait Model [5]. Review of the tackler and ball carrier lower limb joint angles during tackling combined with literature estimates were used to define lumped parameter torque time relationships for the ankle, knee and hip during the tackle phase. Ground reaction and player-to-player tackle contact force penetration characteristics were estimated from first principles as bilinear functions.

For inverse dynamics, a scaled torque-driven version of the [6] rugby model was implemented in OpenSim. The force-time relationship for ground contact/tackling predicted by the MADYMO model were applied in the OpenSim model. The capacity of the MADYMO model to replicate the principal marker trajectories of the ball carrier and tackler were assessed, together with the magnitude of the residual force computed by the OpenSim model. The predicted head angular velocities in the two models were also compared.

III. INITIAL FINDINGS

Figure 1 shows the MADYMO forward dynamics and OpenSim inverse kinematics predictions of ball carrier (left) and tackler (right) kinematics at key timeframes in the tackle. For MADYMO, the inclusion of lumped parameter muscle activation mostly reduces the predicted marker position error, see Table 1.

TABLE I

1 RMS ERRORS IN ACTUATED AND PASSIVE MODEL MARKER TRAJECTORIES UP TO THE TIME OF PEAK TACKLE FORCE

	Actuated model errors (cm)		Passive model errors (cm)	
Marker	Ball carrier	Tackler	Ball carrier	Tackler
Head	1.2	1.5	1.2	1.4
Right shoulder	1.1	1.8	1.4	2.2
Sacral	1.1	0.5	1.7	1.2
Right knee	1	1.7	1.6	1
Right ankle	0.4	1.9	1.1	4.5

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For OpenSim, ball carrier position errors are 19 mm for the head, but 76 mm in the torso, reflecting marker placement challenges in these tests. The MADYMO tackle force and OpenSim pelvis residual moments required for moment balance are shown in Figure 2. The residual should be zero, indicating current challenges with the magnitude/location of the tackle force. The ball carrier's head angular velocity is shown in Figure 3.

20ms – Initial Contact 47ms – Maximum Contact 100ms – Simulation End

Fig. 1. Top row - red marker is MADYMO, light blue markers are Vicon motion capture (dark blue are initial Vicon positions). Bottom row: OpenSim kinematics with tackle and ground force vectors.

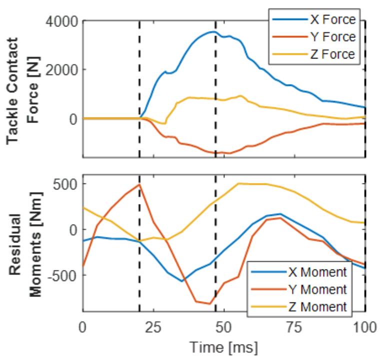

Fig. 2. Tackle force and residual moments.

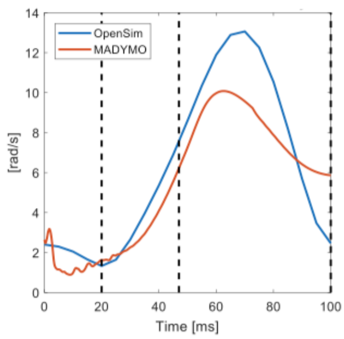

Fig. 3. Head resultant angular velocity.

IV. DISCUSSION

These results show how combining forwards and inverse dynamics can be used to estimate contact force in sporting collisions. In future, application to on-field tackles using markerless motion capture may provide a measure of collision loading to complement wearable sensor data. The results show a benefit of including muscle activation in forward dynamics models of player kinematics during tackling (Table 1) and complement recent inverse dynamics models [6]. The MADYMO ground reaction forces (not shown here) are also more plausible. The approach yields the tackle contact force, though future optimization is needed to reduce residuals and marker position errors. The estimated peak force is nearly 4kN for this staged tackle, and in future this approach could be used to understand the relationship between tackling style and internal body loading as an evidence base for injury prevention strategies.

V. REFERENCES

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