Shorter more regular activity improves cartilage function compared to longer less regular activity

Brian T. Graham[1], Axel C. Moore [2], David L. Burris[1,2], Christopher Price[2,1]
[1]Mechanical Engineering, [2]Biomedical Engineering, University of Delaware, Newark, DE

INTRODUCTION: Excessive inactivity has been associated with cardiovascular disease, metabolic disorders, cancers, and joint disease among other health problems. On this basis, the CDC has recommended 30 minutes of daily activity to maintain health. How these 30 minutes should be distributed throughout each day is an important practical question when considering best workplace practices. Numerous studies suggest that the effects of brief but regular movement on cardiovascular function and insulin sensitivity are superior to those of vigorous exercise following a largely sedentary workday.[1,2] While increased activity in known to decrease risk of joint disease,[3] the potential benefits of hourly 'activity breaks' on cartilage health remain largely unstudied.

The link between exercise and cartilage health is at least partially understood. Static loading during sitting and standing pressurizes the interstitial fluid, which preferentially supports load, reduces friction, and evacuates metabolic waste products.[4] Over time, however, the resulting exudation response defeats interstitial pressure and lubrication.[5] During articulation, cartilage recovers interstitial fluid and pressure as evidenced by reproducible in-vivo observations of joint-space (cartilage) thickening.[6,7] Thus, activity promotes cartilage health by preventing the detrimental mechanical, tribological, and biological effects of dehydration.

Unfortunately, the gold standard for controlled cartilage tribology testing, the stationary contact area, induces exudation without providing any mechanism for competitive recovery.[5] As a result, realistic studies of the link between cartilage tribology and health have been difficult to date. We recently showed that by enlarging the cartilage sample to create a convergent wedge at the leading edge of the stationary contact area (cSCA) led to sliding-induced fluid recovery similar to that observed in-vivo.[8] Our follow-up studies suggest that sliding-induced hydrodynamic pressures restore hydration by competing directly against the load-induced exudation process.[9] Here, we leverage the cSCA testing configuration to determine if and how the distribution of 30 min. of sliding affects dehydration, which we use as a real-time predictor of cartilage health, within a simulated day.

METHODS: 19 mm diameter osteochondral cylinders (n = 6) were harvested from the femoral condyles of mature bovine stifles and tested on a uni-directional pin-on-disc materials tester. When compressed against the glass disc, the curvature of the cartilage explants creates a convergence zone at the contact periphery that permits hydrodynamic effects necessary for TR. Since the contact area is kept stationary relative to the cartilage, this geometry is referred to as a convergent stationary contact area (cSCA). Explants were subject to a 150-min 'equivalent day' (based on area-exudation time scaling) of activity split into a 5N load during the 'awake' period and a 0.1N load during the 'sleep' period (Figure 1A). The awake period was further divided into a 30 min active (100mm/s sliding) and 60 min inactive period. Thirty min. of total daily sliding was distributed into 1, 3, 6, or 15 equally spaced bouts.

RESULTS: The data in Figure 1A illustrates the effects of load, sliding, and resting on the deformation and recovery responses of cartilage. When loaded statically, the deformation jumps more or less immediately to 100 µm, which represents the elastic response of cartilage. Over time under static load, deformations increase due to wring-out. Subsequent sliding restores thickness via tribological rehydration nearly to the original 'elastic' limit of 100 µm; this rehydration process restores interstitial pressure and lubrication (not shown).

Increasing the regularity of 30 min. of daily activity substantially reduced the total loss of interstitial fluid as illustrated by Figure 1B. Increasing the number of bouts from 1 (daily) to 15 (hourly) decreased the loss of interstitial fluid by 80% and decreased the loss of interstitial lubrication by a similar extent (not shown).

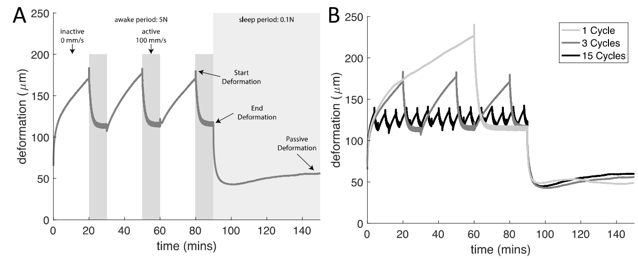

Figure 1 - A) Typical cartilage deformations during highlighted portions of the experiment. B) Deformation in a representative sample during 3 different activity cycles.

DISCUSSION: Limiting the time for exudation under static conditions also limited the loss of the interstitial fluid from cartilage; this result could have been anticipated based on well-established theory.[4,5] However, it could be similarly reasoned that proportionally reduced sliding times should have limited the rehydration time and any potential benefit from increased regularity. The results demonstrate that reduced sliding time did not impede recovery and highlight the competitive nature of the tribological rehydration process relative to exudation.

Recent studies have shown that 10 min of walking is sufficient to 'normalize' the detrimental effects of prolonged sitting on vascular function.[1] In this case, two min. of sliding was sufficient to reverse the detrimental effects of the exudation process. More importantly, this study demonstrates that sliding, no matter the duration, can prevent the significant and detrimental dehydration effect of prolonged inactivity. This suggests that the regularity of the activity is far more important than the duration of activity, which is consistent with the message from the most recent research on cardiovascular disease.[2] It is quite remarkable that these disparate systems appear to respond in similar ways to patterns of activity.

The cSCA of the present study neglects many important features of the whole joint including the known effects of migrating and the gemini interface. Migration, for example, periodically exposes the loaded zone to the bath thereby enabling free-swelling. The cSCA of the present study eliminated this well-established contributor. Nonetheless, the sliding-induced recovery response observed here is remarkably consistent with the articulation-induced recovery response observed in whole joints. While osmotic swelling is known to promote the recovery of the migrating surface outside the contact zone, these results suggest that tribological rehydration contributes significantly to the rehydration of the migrating and stationary surfaces within the loaded zone.

REFERENCES: 1. Restaino, *Exp. Physiol.* (2015), 2. Duvivier, *PLoS One* (2013), 3. Williams, *Med. Sci. Sport. Exerc.*(2013), 4. Mow, *J. Biomech.* (1984), 5. Ateshian, *J. Biomech.* (2009), 6. Ingelmark,*Upsala Lakareforen. Forh.* (1948) 7. Eckstein, *J. Anat.* (2006), 8. Moore, *Osteoarthr. Cartil.* (2017), 9. Graham, *Osteoarthr. Cartil.* (2017)