INTRODUCTION
Finite element analysis of a knee joint is time-consuming because of the complex knee geometry and multiple mechanical contacts involving femur, tibia, patellar, menisci, femoral and tibial cartilages. To simplify the problem, elastic models of cartilage and meniscus ignoring fluid flow have been extensively used in the joint modeling. It is believed that an elastic model can be used to describe the instantaneous load response of the knee (or knee response to fast loading), if an equivalent Young's modulus is applied. The equivalent modulus must be greater than the actual modulus of the tissue matrix, because the fluid trapped in the matrix stiffens the tissue. In addition, the equivalent Poisson’s ratio is set to close to 0.5 to approximate the tissue incompressibility at fast compression.

The equivalence of instantaneous response to elastic behavior may be simply established in the linear mechanics of porous media. For example, applying the linear biphasic theory to unconfined compression testing, the equivalent modulus for instantaneous compression is 1.5E/(1+ν), where E and ν are the modulus and Poisson’s ratio for the tissue matrix. However, in 3D nonlinear mechanics involving material anisotropy, such as for the knee joint, the equivalence cannot be simply established. The objective of the present study was to determine whether an elastic model can still describe the instantaneous load response of the knee when a large “equivalent” Young’s modulus is used.

METHODS
An anatomy-accurate knee model was previously constructed using MRI measured geometry. The bone was modeled as elastic because of its greater stiffness as compared to the cartilaginous tissues. Fluid flow and site-specific nonlinear fibril-reinforcement were considered for the cartilages and menisci. Mechanical contact allowing small frictional sliding was modeled between the following pairs using ABAQUS: femoral and tibial cartilages, femoral cartilage and meniscus, meniscus and tibial cartilage. Knee compression without flexion was simulated.

Finite element solution was first obtained using the proposed model including fibril reinforcement and fluid pressure (referred as viscoelastic solution). The instantaneous response was approximated by sealing all tissue surfaces with impermeable boundary conditions and using virtually zero permeability. An elastic model assuming no fluid pressure was then employed using the same fiber properties, a Poisson’s ratio of 0.48 and a large equivalent modulus for the nonfibrillar matrix of cartilage or meniscus (referred as elastic solution). The equivalent modulus was determined by matching the total forces predicted by the two models for the given compression. The modulus is commonly determined this way in published studies when the force data is available, and finite element analysis is desired for contact pressure etc.

RESULTS
The viscoelastic solutions were obtained using a Young’s modulus of 0.26 MPa and a Poisson’s ratio of 0.36 for the nonfibrillar matrix. These elastic properties are typical for articular cartilage when collagen fiber properties are additionally added. While the Poisson’s ratio for the elastic model was set to 0.48, the equivalent modulus was found to be 1.22 MPa, which makes a match in force at 100 μm compression. If the equivalent Young’s modulus was altered to 12 MPa, a moderate value as compared to the cartilaginous tissues. Fluid flow and site-specific nonlinear fibril-reinforcement were considered for the cartilages and menisci. Mechanical contact allowing small frictional sliding was modeled between the following pairs using ABAQUS: femoral and tibial cartilages, femoral cartilage and meniscus, meniscus and tibial cartilage. Knee compression without flexion was simulated.

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DISCUSSION
There is no doubt over the equivalence of the instantaneous load response of soft tissue to an elastic behavior. Such equivalence is suggested by the fundamentals of the mechanics of porous media. Therefore, a properly formulated elastic model should be able to approximate the load response of the knee to fast loadings. The question is how to establish the equivalence in terms of equivalent material properties. They are deformation dependent, as demonstrated here. We may need to reexamine the traditional method using a constant equivalent modulus to find the equivalence. As indicated in the present study, we could not obtain the same contact pressure and displacement using the equivalent modulus. It may be possible that equivalent Poisson’s ratios, other than a value close to 0.5, must also be found. In fact, this is the case for thin plates, when linear Biot theory is applied.

In conclusion, an elastic model of articular cartilage has limited ability in predicting mechanical behavior of the knee to fast loading, if the equivalence is not numerically established. The proposed model accounting for the fluid pressure is more time-consuming than the elastic model, but has the potential to provide further or more precise information.

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