Comparison of Torsional Stiffness of Orthotics Made From Different Materials

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Introduction:

Arch supports have been a mainstay of foot orthopedics for over 100 years. Many theories have been advanced and various methods of molding, prescribing and fabricating have been utilized. The original Whitman plates were made of stainless steel. Later, people started utilizing softer materials due to complaints of steel being too hard. In the 1960s, to emphasize that the support under the foot should be considered to be a dynamic rather than a static type of support, the term "foot orthosis" started being utilized rather than the term "arch support." The use of orthotics to reduce symptomatology and change foot kinematics and kinetics has been well documented, though the results have not been consistently in favor of custom-made orthoses.

Podiatry today mainly utilizes various forms of the Root orthotic, which incorporates custom molding, and also ideas of Steindler (1929) who advocated the use of a varus wedge under the heel of the shoe and a valgus wedge under the forefoot to correct a flatfoot. The Root orthosis takes a mold of the neutral foot with the midtarsal joint fully pronated. The orthotic is made from a "rigid" or "semi-rigid" material and hugs the medial side of the heel in order to produce a varus torque on the heel. By molding the orthotic to the forefoot with the forefoot fully everted, the "rigid" orthotic provides an eversion force against the forefoot that keeps it comfortable. It also allows the peroneus brevis to lift the lateral side of the foot and transfer weight to the medial side.

A great many of the orthotic efficacy studies have utilized "rigid" or "semi-rigid" to describe the stiffness of the orthotic materials, yet no author has defined what the terms "rigid" or "semi-rigid" mean. The majority of the studies have utilized orthotics fabricated from polypropylene, yet none of the authors have given any reason for selecting the material or the thickness. The principle investigator contacted many of these researchers to find out what type of algorithm was used in selecting the material type and thickness, and none had any such algorithm. In 2011, the PI surveyed 20 colleagues in the VA about their preference for orthotic materials. The result was that polypropylene was favored by a majority, though none were able to give any reason for their preference.

Currently, every orthotic manufacturer has their opinion about the perfect orthotic material, yet it is difficult to obtain any information about the properties of those materials. Most orthotic companies give the practitioner choices about the qualitative flexibility, but these terms, such as "flexible", "semi-rigid" and "rigid" have no quantitative meaning. The principle investigator over the past several years has found in clinical practice that changing orthotic stiffness properties can greatly affect the success of the orthotic.

In a preliminary project, the PI took pictures of his own foot standing on a pair of the most rigid custom made acrylic orthotic that a well-known orthotic company makes. (Figure 1-4) It is readily seen that this material is definitely not rigid and that it is flexing more on the lateral side than on the medial side. This means that the orthotic is not producing the valgus rotation of the forefoot that it was designed to produce.

The goal of this research proposal is to investigate torsional stiffness of orthotics made from a variety of the rigid and semi-rigid materials, and to create a database that other practitioners may draw upon to make better decisions about material choice.

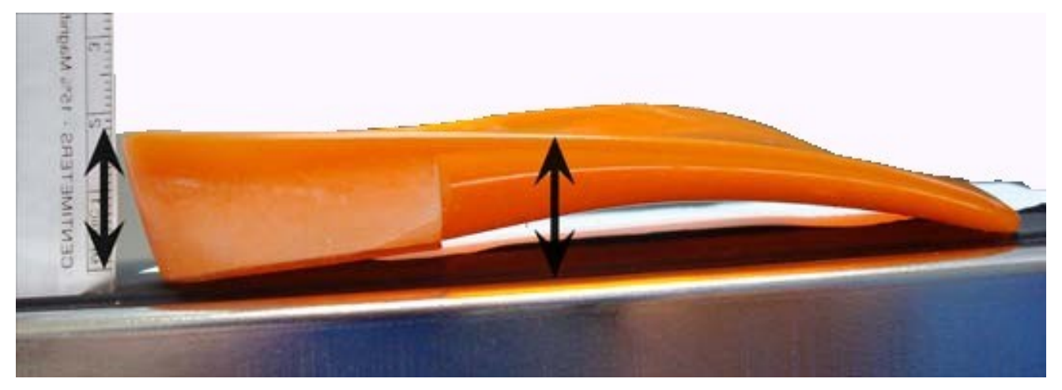

Figure 1: Acrylic Orthotic non-weightbearing with lateral arch height of 18mm.

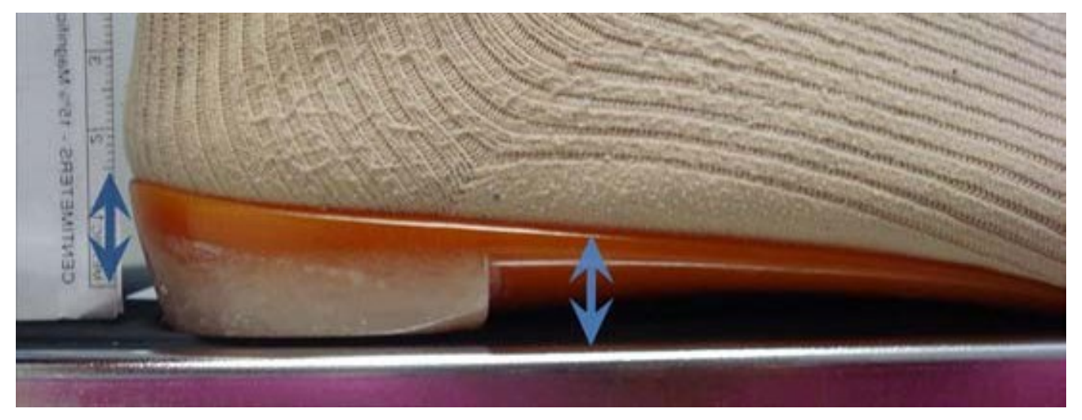

Figure 2: Acrylic Orthotic with subject standing on it. Lateral arch height is 4mm less, at 14mm.

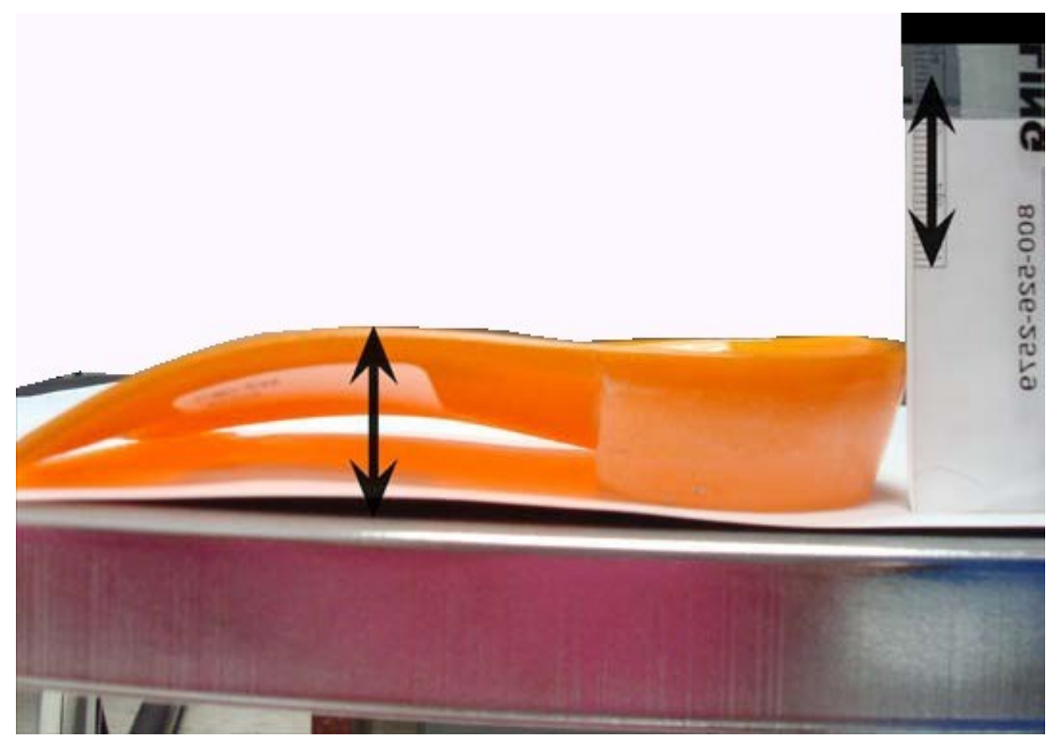

Figure 3: Acrylic Orthotic non-weightbearing with medial arch height of 26mm.

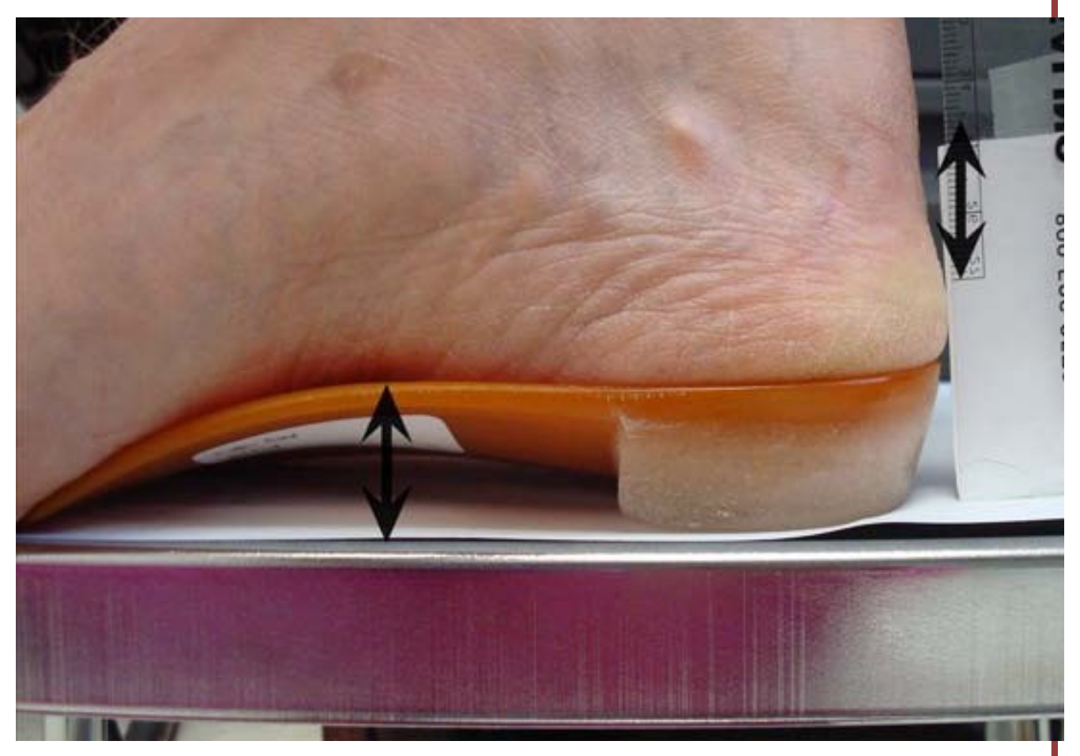

Figure 4: Acrylic Orthotic with subject standing on it. Medial arch height is 2mm less, at 24mm.

Disclaimer:

The research is currently being conducted at the Orlando Veterans Administration Medical Center with the approval of the Medical Center's Research Committee. Any opinions expressed here are those of the authors alone and in no way reflect an endorsement of the US Department of Veterans Affairs or any other branch of the United States Government.

Methods and Materials:

The custom-made orthotics tested in this project have to be made from a "rigid" or "semi-rigid" material and must have a noncompressible heel post. The orthotics are tested before they have been dispensed to the patient for wearing. A total of 100 orthotics will be tested.

Testing is performed by two independent testers with the 3rd member of the team performing statistical analysis.

The testing procedure for each orthotic is as follows: The orthotic material is recorded, and the following measurements are made prior to testing: 1) the maximum medial arch height, 2) the maximum lateral arch height, 3) the width of the orthotic in the center, 4) the thickness of the orthotic, and 5) the length of the orthotic from the anterior heel post to front clamp. The orthotic is clamped to a solid table with the heel post set flat on the surface of the table and the anterior edge hanging off the edge of the table. A clamp is attached to the front edge of the orthotic that has a 7/16" bolt head aligned with the center line of the orthotic. A digital angle finder is taped to the top of the clamp and set to 0º when the orthotic is at rest.

A clique-style torque wrench with 7/16" socket is fitted over the bolt head, and the anterior edge of the orthotic is slowly inverted until the torque wrench cliques, which means that the pre-set torque has been reached. (Figure 5) At this point the angle of the forefoot clamp is read from the angle finder. The test is then repeated in the eversion direction until will the wrench cliques at the preset torque. The angle of forefoot eversion is then read from the digital angle finder.

The initial setting for the torque wrench is at 5 inch-pounds. After testing inversion and eversion angles with this torque, the wrench is increased by 5 inch-lbs increments to a maximum of 75 inch-pounds of torque. Each tester performs a total of 7 trials on each orthotic. A statistician is able to determine that the trials are unbiased. The average of all 14 trials for the orthotic is accepted as the true value of the angular deflection with a each increment of torque.

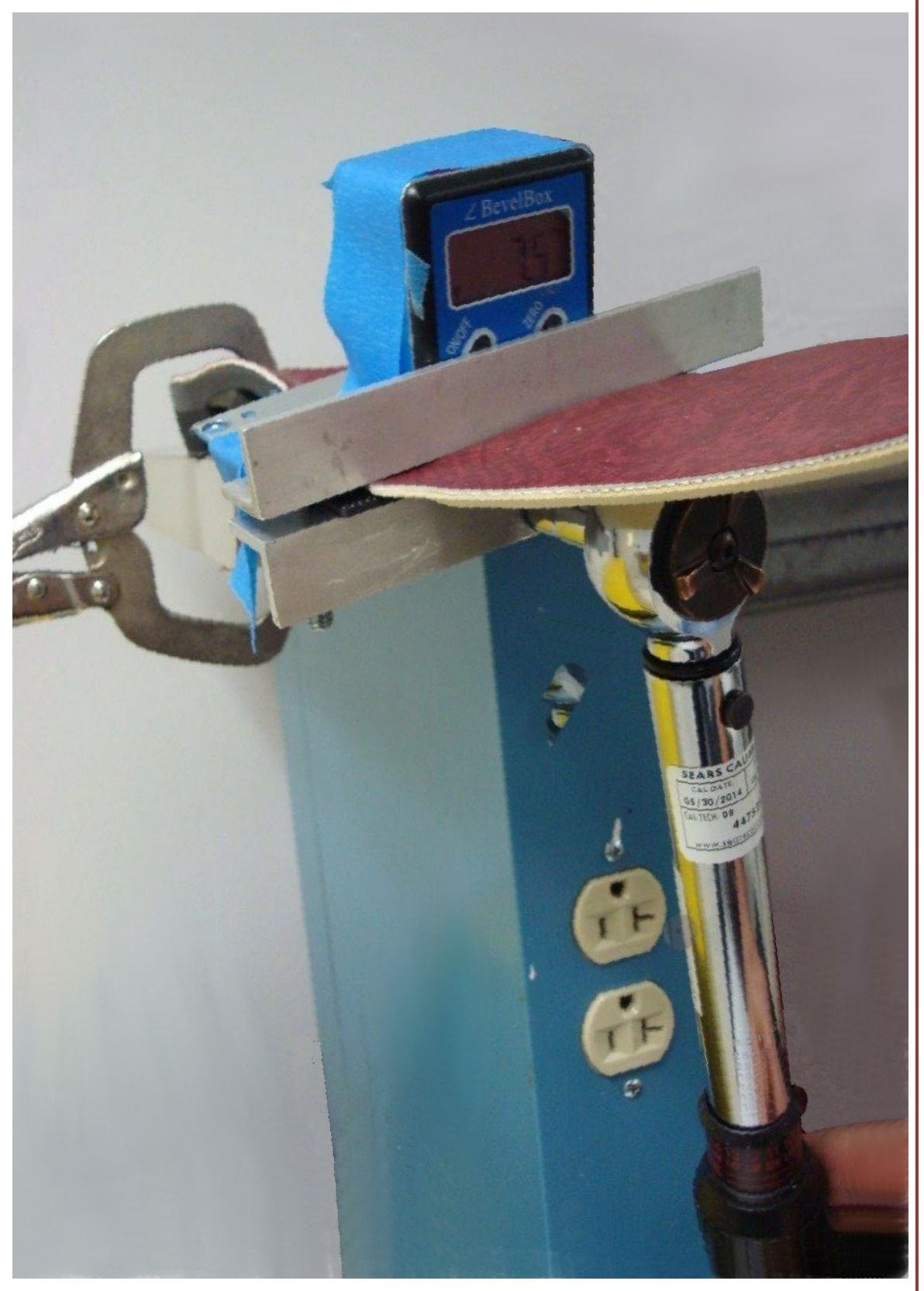

Figure 5: Test apparatus showing orthotic clamped to table top, and a clamp across the forefoot. A digital angle finder is attached to the top. The orthotic is twisted with a torque wrench fit to a bolt head on the front of the forefoot clamp that allows the forefoot of the orthotic to be inverted then everted against the rearfoot.

Results:

To date, the research project is 15% completed. This report shows the results of only two orthotics tested, one made from acrylic and one made from polypropylene. Both were comparable in cross sectional area. The dimensions for the two orthotics are shown in Table 1.

A graph of the average toque vs. deflection angle for the inversion direction is shown in Figure 6 for the polypropylene and acrylic. A graph of the average torque vs. deflection angle for the eversion direction is shown in Figure 7, comparing the polypropylene and acrylic material.

Table 1

Material	Medial arch height (cm)	Lateral arch height (cm)	Length (cm)	Width (cm)	Thickness (cm)	Cross Sectional area (cm^2)	Polar Moment of Inertia (cm^4)
Polypropylene	1.48	0.75	10.48	8.03	0.47	3.77	20.35
Acrylic	2.33	1.04	10.92	7.68	0.50	3.84	18.95

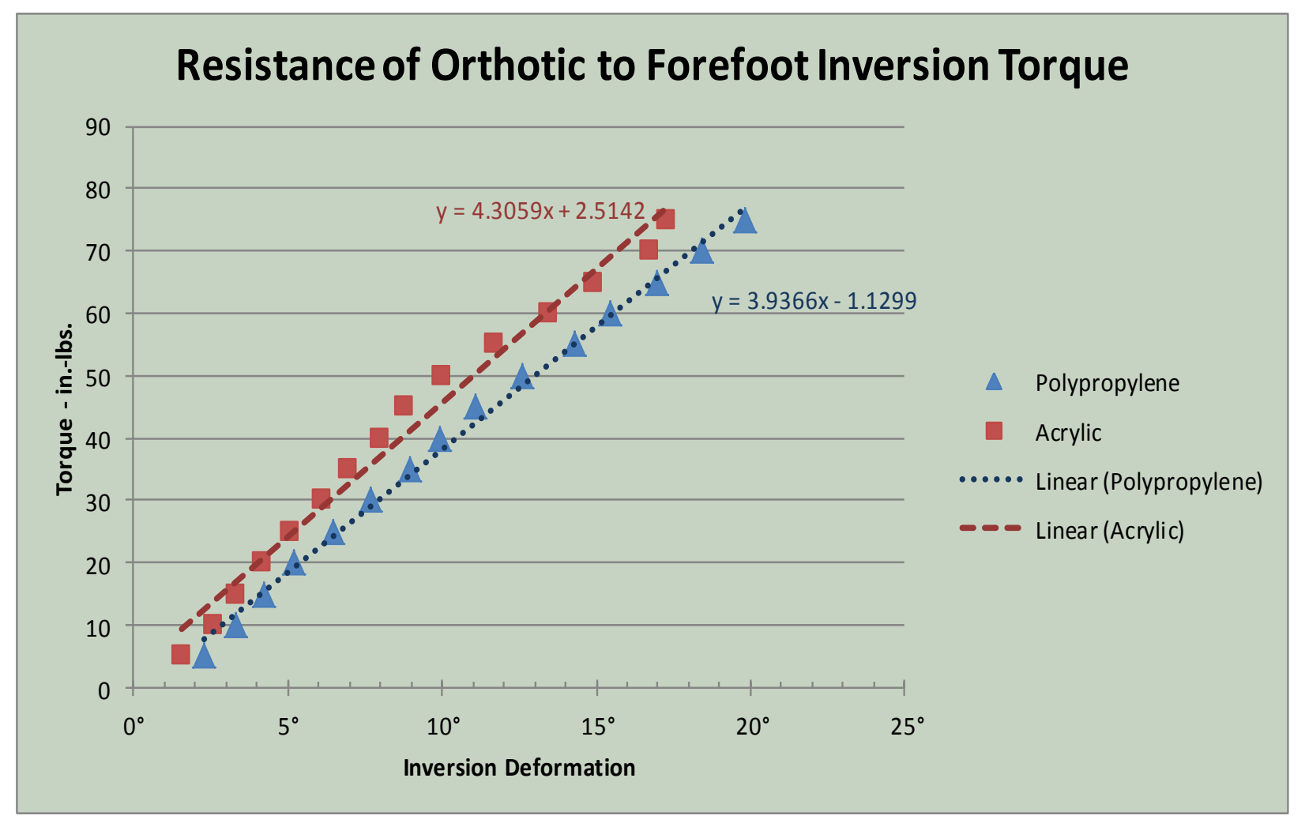

Figure 6: A graph showing the average resistance of the polypropylene and the acrylic orthotics to a torque attempting to invert the forefoot to the rearfoot. It is seen that the acrylic is only mildly more resistant to a forefoot inversion torque than the polypropylene material. The graphs approximate a linear fit, though a quadratic fit is more precise and suggests that both orthotics are mildly non-linear when they are new.

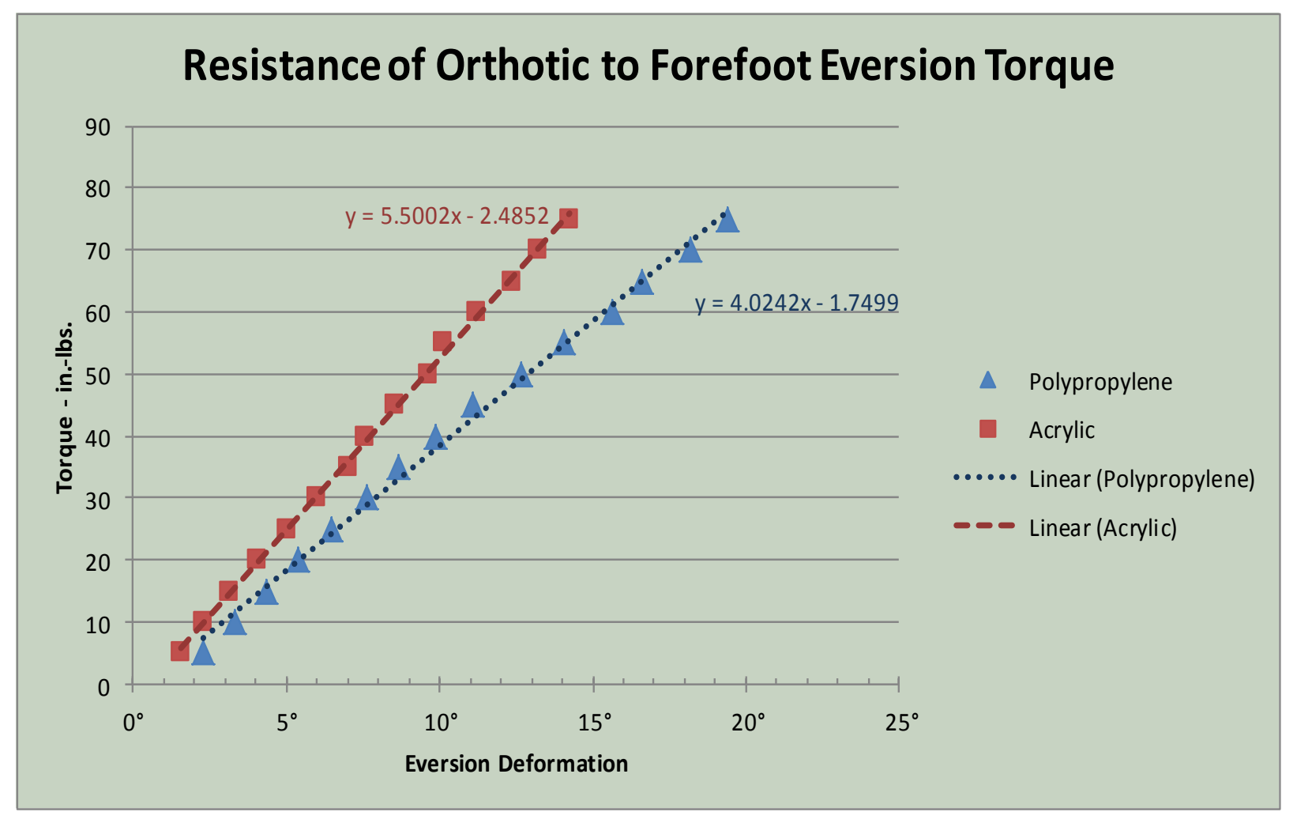

Figure 7: A graph showing the average resistance of the polypropylene and the acrylic orthotics to a torque attempting to evert the forefoot to the rearfoot. In this case, the acrylic is much more resistant to eversion than the polypropylene. Again both curves are close to linear, but a quadratic fit is even more precise.

Comparison with the above graph shows that the polypropylene is only slightly more flexible in the inversion direction than in the eversion direction, however the acrylic is much more flexible in the inversion direction than the eversion direction. Further statistical analysis will be able to determine whether this is a function of the material alone or whether this is a function of the differences in the curvatures.

Discussion:

Figure 8: High degree of rearfoot pronation.

It has long been recognized that for the plantigrade foot, all of the metatarsal heads touch the ground. Figure 8 shows a classic severely pronated foot. In this case, the forefoot is inverted to the rearfoot the same number of degrees that the rearfoot is everted from perpendicular. An orthotic, therefore, that tries to control the rearfoot from everting from perpendicular, must prevent the forefoot from inverting to the rearfoot. If it lacks this resistance, then the patient will still pronate into the orthotic, which will cause it to feel uncomfortable. The more an orthotic can resist the forefoot to rearfoot inversion, the more likely it will be able to resist the patient's rearfoot pronation.

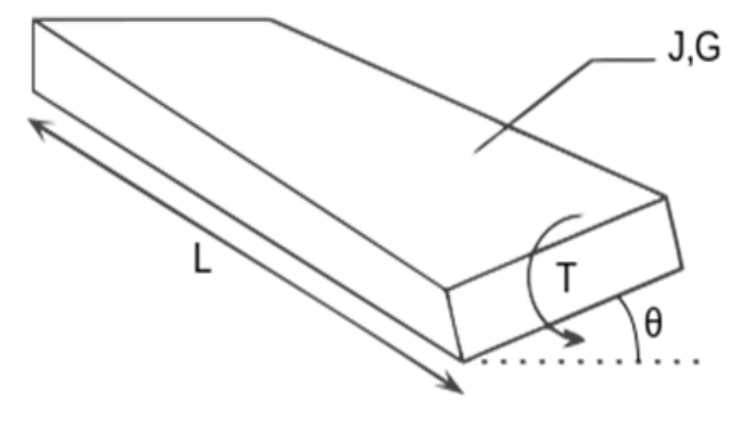

Figure 9: A flat plate resisting torsion

Figure 9 represents the torsional modulus or rigidity of a flat plate, which most orthotics are made from. The modulus of torsional (or shear) rigidity is given the letter "G". The formula to determine "G" is:

$$G = \frac{T * L}{\theta * J}$$

T = the torque applied
L = the length of the object
θ = the angle the objecf distorts
J = the polar moment of inertia

The polar moment of inertia is critical, because it is based on the 4th power of the outside dimensions.

For a rectangular plate, the equation is : $J = \frac{a^3 b + ab^3}{12}$

Where *a* and *b* are the width and height of the cross sectional rectangle.

While Table 1 shows that the cross sectional areas of the two orthotics are almost identical, the acrylic orthotic has a smaller polar moment of inertia which would decrease G. Applying these above formulas to calculate G, assuming that the material is linear, we arrive at the values in Table 2.

Table 2

Material	G: Inversion	G: Eversion
Polypropylene	1312	1342
Acrylic	1606	2052

As can be seen in Table 2, the acrylic orthotic is about 19% more resistant to the torque that tries to invert the forefoot against the rearfoot. On the other hand, it is about 53% more resistant to the torque that tries to evert the forefoot against the rearfoot. This suggests that the acylic orthotic will mildly resist rearfoot pronation more than the polypropylene, but it will markedly resist rearfoot supination more than the polypropylene.

This project is still in its early stages of data collection. Additional analysis will be performed to to better understand how medial and lateral arch heights increase or decrease the stiffness of the orthotic. With additional data, it is should be possible for practitioners to optimize the selection of orthotic materials for the wide variety of foot morphologies and kinematics they encounter.

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