# Role of the Vitreous in Ocular Biomechanics

# O Papel do Vítreo na Biomecânica Ocular

João Heitor Marques[1], Pedro Manuel Baptista[1], João Coelho[1], Maria João Meneres[1], Angelina Meireles[1], João Melo Beirão[1]

[1] Serviço de Oftalmologia, Centro Hospitalar Universitário do Porto, Porto, Portugal

**Recebido/Received:** 2021-11-24 | **Aceite/Accepted:** 2022-10-06 | **Publicado/Published:** 2022-12-31

*© Author(s) (or their employer(s)) and Oftalmologia 2022. Re-use permitted under CC BY-NC. No commercial re-use.*
*© Autor (es) (ou seu (s) empregador (es)) e Oftalmologia 2022. Reutilização permitida de acordo com CC BY-NC. Nenhuma reutilização comercial.*

**DOI:** https://doi.org/10.48560/rspo.25884

## ABSTRACT

**INTRODUCTION:** Characterization of ocular biomechanics is necessary to fully understand the development of vitreoretinal traction, retinal tears, and detachment. Few studies have tried to characterize the viscoelastic properties of the vitreous and all previous studies have used either *ex vivo* human eyes or *in vivo* animal eyes. Our objective was to analyze, *in vivo*, the role of the vitreous in ocular biomechanics.

**MATERIAL AND METHODS:** Prospective longitudinal study that included 24 patients submitted to unilateral pars plana vitrectomy (PPV) for vitreous opacities or epiretinal membrane. Ocular biomechanics were analyzed with Oculus Corvis ST® one week before and one month after surgery. The whole eye movement (WEM) was analyzed separately as a function of posterior segment compression. Posterior vitreous detachment (PVD) was access with 55º optical coherence tomography. The fellow non-operated eyes were used as control. Non-parametric tests were used, and the significance level was set at 5%.

**RESULTS:** After PPV, we observed changes in biomechanics towards a softer corneal behavior, namely a reduction in SP-A1 ($p$=0.009). However, intraocular pressure (IOP) was also lower ($p$=0.034). WEM distance decreased after vitrectomy ($p$=0.020). There were no significant differences in fellow non-operated eyes. A cross-sectional comparison before PPV showed that eyes with PVD at the macula also have a shorter WEM distance ($p$=0.047). There were no significant differences according to the reason for PPV (vitreous opacities in 16 eyes or epiretinal membrane in 8 eyes).

**CONCLUSION:** This study shows changes in response to an air pulse after PPV, which suggests a role of the vitreous in ocular biomechanics. Due to lower IOP after surgery, no definite conclusions may be drawn regarding corneal measurements and indexes. More importantly, we observed changes that relate to the posterior segment of the eye, namely the vitreous. A decrease in WEM distance conveys a reduction in anterior-posterior deflection and reduced compression of the posterior segment. Lower IOP alone would produce the opposite effect. Eyes with PVD may also have reduced WEM. Together these findings demonstrate, for the first time *in vivo*, that the attached vitreous exerts a centripetal force on the globe.

**KEYWORDS:** Biomechanical Phenomena; Kinetics; Posterior Eye Segment; Vitreous Body; Vitreous Detachment.

## RESUMO

**INTRODUÇÃO:** A biomecânica ocular faz parte da fisiopatologia vítreo-retiniana, nomeadamente da tração vítreo-retiniana, rasgaduras de retina e descolamentos de retina. Os poucos estudos publicados que tentaram caracterizar a biomecânica do vítreo utilizaram métodos *ex vivo* em seres humanos ou *in vivo* em animais. O objetivo deste estudo foi analisar, *in vivo*, o papel do vítreo na biomecânica ocular.

**MATERIAL E MÉTODOS:** Estudo prospetivo longitudinal que incluiu 24 doentes com indicação clínica para vitrectomia pars plana (VPP) em um dos olhos por opacidades do vítreo associadas a amiloidose hereditária por transtirretina ou por membrana epirretiniana primária. A biomecânica ocular foi analisada com o Oculus Corvis ST® uma semana antes e um mês após a cirurgia. O movimento ocular global (MOG), como medida da compressão do segmento posterior, foi analisado separadamente dos índices biomecânicos corneanos. A presença prévia de descolamento posterior do vítreo (DPV) foi analisada com tomografia de coerência ótica de campo alargado (55º). Os olhos adelfos (não-operados) foram usados como grupo de controlo. Os testes estatísticos utilizados foram não-paramétricos e o nível de significância foi definido em 5%.

**RESULTADOS:** Após a VPP, os índices biomecânicos da córnea alteraram no sentido de um comportamento menos rígido, nomeadamente a redução do SP-A1 ($p$=0,009). No entanto, a pressão intraocular (PIO) também diminuiu ($p$=0,034). Verificou-se uma redução da distância do MOG após VPP ($p$=0,020). Não houve diferenças nos olhos adelfos. Numa analise transversal da visita pré-operatória, os olhos com DPV macular também apresentaram menor distância do MOG ($p$=0,047). Não houve diferenças relativamente ao motivo para a VPP (opacidades vítreas em 16 olhos e membrana epiretiniana em 8 olhos).

**CONCLUSÃO:** Este estudo preliminar mostrou diferenças no movimento dinâmico do olho ao aplicar uma força externa, o que sugere que o vítreo tem um papel significativo na biomecânica ocular. Como a PIO foi mais baixa após a cirurgia, não é possível chegar a conclusões relativamente às diferenças na biomecânica corneana. O nosso achado mais importante foi a redução do MOG após VPP, o que pode estar relacionado com o segmento posterior e nomeadamente com o vítreo. Uma diminuição no MOG traduz uma redução na deflexão ântero-posterior e consequentemente uma redução na compressão do segmento posterior. A PIO mais baixa, isoladamente, iria ter o efeito oposto. Os olhos com DPV também mostraram um MOG mais reduzido. Assim, os nossos resultados mostram, pela primeira vez *in vivo*, que o vítreo exerce uma força centrípeta no globo ocular.


**PALAVRAS-CHAVE:** Cinética; Corpo Vítreo; Descolamento do Vítreo; Fenómenos Biomecânicos; Segmento Posterior do Olho.

## INTRODUCTION

The vitreous humor (vitreous) is a complex tissue that fills the posterior segment of the eye, between the lens and the retina. The vitreous has developmental, optical and nutritional functions.[1,2] Additionally, the vitreous provides mechanical protection to ocular deformation, namely eye movements, saccades, head accelerations and decelerations, and external impacts.[3,4] The molecular content of the vitreous is well described: it is composed mainly of water (99%), heterotypic collagen fibrils and hyaluronan.[5] More importantly, the supramolecular organization of those components is responsible for transparency and it is the key to understand vitreous physiology and pathology.[6] However, analyzing the supramolecular structure and studying its biomechanics is much more challenging, especially *in vivo*. Quoting J. Sebag in his many reports about the vitreous, "it is a quest to see the invisible".

The vitreous structure is dynamic along its lifetime and several ocular pathologies such as retinal tears, rhegmatogenous or tractional retinal detachment, macular edema and vitreous hemorrhage may be seen as vitreous related complications. Characterization of vitreous biomechanics is therefore necessary to fully understand, prevent and improve the treatment of these conditions. Moreover, developments in the study of the vitreous may optimize the design and control of surgical instruments and techniques.

Few studies have tried to characterize viscoelastic properties of the vitreous, but all have used either *ex vivo* human eyes or *in vivo* animal eyes.[7-10]

Our objective was to analyze, *in vivo*, changes in ocular biomechanics, comparing eyes before and after surgical removal of the vitreous.

# METHODS

## STUDY DESIGN AND PARTICIPANTS:

Prospective longitudinal study in Centro Hospitalar Universitário do Porto, Porto, Portugal, that included 24 consecutive subjects with indication for unilateral *pars plana* vitrectomy (PPV) for primary epiretinal membrane or vitreous opacities. Exclusion criteria were systemic collagen disorders, corneal scarring, previous cornea refractive surgery, intraocular surgery, previous ocular trauma, glaucoma, or use of contact lenses, as these conditions may influence ocular and vitreous biomechanics. Exclusion criteria were applied bilaterally. Subjects underwent PPV only or with membrane peeling (not combined with other procedures such as cataract surgery, cryotherapy, endocular photocoagulation or gas tamponade) by a single surgeon.

## STUDY PROTOCOL:

All subjects underwent a measurement of ocular biomechanics in both eyes with Oculus Corvis ST, by a trained technician, one week before and one month after surgery. The Corvis ST is an ultrahigh-speed Scheimpflug camera that records and analyzes the anterior segment of the eye when an air puff is released. The cornea first flattens (A1), then becomes concave (HC), flattens again (A2), and then returns to its original contour. At the same time, the posterior segment undergoes an anterior-posterior compression. In the moment the corneal returns to its original shape, the rest of the globe is still compressed, and the complete anterior segment is displaced posteriorly. From this displacement, the whole eye movement (WEM) is calculated, as a reproduction of posterior segment movement. Given that cornea deformation equals cornea deflection plus WEM, the outcomes considered were timing and deflection distance, at each moment. Deformation values were not considered as they are dependent on WEM, that was analyzed separately. Each examination consisted of the mean of three measurements and only examinations with Quality Score "OK" were accepted.

Posterior vitreous status was assessed with 55º spectral domain optical coherence tomography (Heidelberg Spectralis®) and defined as complete attachment, macular detachment, papillary detachment, or complete detachment.

## DATA ANALYSIS:

Eyes were considered the statistical unit but only the operated eyes (1 eye per subject) were included for analysis. The fellow non-operated eyes were used only for a control longitudinal test. Descriptive statistics are shown as mean ± standard deviation [minimum -maximum]. Non-parametric tests were used, and the significance level was set at 5%.

## Ethical considerations

This study was performed accordingly to the principles of the Declaration of Helsinki. Moreover, all exams performed are considered non-invasive. Eligible participants were enrolled after obtaining their acceptance and written informed consent for the study and for publication. The study was approved by our institutional review board and ethics committee (ID number 2021.037(029-DEFI/030-CE). All data was saved and shared anonymously.

# RESULTS

The indications for vitrectomy were vitreous opacities associated with transthyretin amyloidosis in 15 eyes and epiretinal membrane in 9 eyes. The mean age of the 24 included patients was 50.6 ± 8.1 [42.6 - 66.1]. Gender distribution was 4 women / 20 men. All subjects were phakic. Refractive error in ranged between -0.75D and +1.75D. There were no intraoperative or postoperative complications during the follow-up.

Table 1 shows associations between age and preoperative measurements. Considering eyes without PVD only, there was no significant association between age and WEM (Spearman's rho=0.333; $p$=0.207). There were no significant differences in preoperative biomechanical measurements according to the reason for vitrectomy as detailed in Table 2.

**Table 1. Associations between age and preoperative measurements.**

| Associations with age (years) | | |
|---|---|---|
| | **Spearman's rho** | ***p*-value** |
| IOP [mmHg] | 0.059 | 0.785 |
| bIOP [mmHg] | -0.471 | **0.020** |
| Pachymetry [µm] | 0.941 | **<0.001** |
| A1 Time [ms] | 0.059 | 0.785 |
| A1 Deflection Amp. [mm] | -0.294 | 0.163 |
| A2 Time [ms] | 0.118 | 0.584 |
| A2 Deflection Amp. [mm] | 0.588 | **0.003** |
| HC Deflection Amp. [mm] | -0.118 | 0.584 |
| HC Time [ms] | -0.313 | 0.136 |
| Max Deflection Time [ms] | 0.824 | **<0.001** |
| Max Deflection Amp. [mm] | -0.059 | 0.785 |
| SP-A1 | 0.941 | **<0.001** |
| SSI | 0.118 | 0.584 |
| Max. WEM Time [ms] | 0.059 | 0.785 |
| Max. WEM Distance [mm] | -0.176 | 0.409 |

IOP - intraocular pressure; bIOP - biomechanical-corrected; A1 - first applanation; (A2) second applanation; HC - moment of highest concavity; Max - maximum; Amp - amplitude; SP - A1 stiffness parameter A1; SSI - stress-strain index; WEM - whole eye movement; SD - standard deviation.

**Table 2. Cross-sectional comparison of preoperative biomechanical measurements in eyes operated because of epiretinal membrane or vitreous opacities.**

| | Reason for vitrectomy | | | | |
|---|---|---|---|---|---|
| | Epiretinal membrane (n=9) | | Vitreous opacities (n=15) | | *p*-value |
| | Mean | SD | Mean | SD | |
| Age [years] | 51.395 | 9.173 | 50.125 | 7.630 | 0.830 |
| IOP [mmHg] | 15.278 | 1.839 | 15.100 | 1.466 | 1.000 |
| bIOP [mmHg] | 14.267 | 1.491 | 14.267 | 1.315 | 0.646 |
| Pachymetry [µm] | 550.889 | 25.634 | 546.533 | 22.347 | 0.830 |
| A1 Time [ms] | 7.787 | 0.229 | 7.756 | 0.189 | 0.481 |
| A1 Deflection Amp. [mm] | 0.088 | 0.010 | 0.091 | 0.009 | 0.646 |
| A2 Time [ms] | 21.934 | 0.319 | 21.988 | 0.301 | 0.646 |
| A2 Deflection Amp. [mm] | 0.090 | 0.013 | 0.093 | 0.013 | 0.646 |
| HC Deflection Amp. [mm] | 0.808 | 0.057 | 0.824 | 0.058 | 0.819 |
| HC Time [ms] | 17.120 | 0.214 | 17.140 | 0.217 | 0.646 |
| Max Deflection Amp. [ms] | 0.811 | 0.057 | 0.829 | 0.058 | 0.481 |
| Max Deflection Amp. [mm] | 16.824 | 0.370 | 16.745 | 0.304 | 0.646 |
| SP-A1 | 122.874 | 22.859 | 115.796 | 19.528 | 0.646 |
| SSI | 1.177 | 0.134 | 1.155 | 0.113 | 0.481 |
| Max. WEM Time [ms] | 21.880 | 0.681 | 22.088 | 0.820 | 0.830 |
| Max. WEM Distance [mm] | 0.280 | 0.034 | 0.285 | 0.035 | 0.830 |

IOP - intraocular pressure; bIOP - biomechanical-corrected; A1- first applanation; A2 - second applanation; HC - moment of highest concavity; Max - maximum; Amp - amplitude; SP-A1 - stiffness parameter A1; SSI - stress-strain index; WEM - whole eye movement; SD - standard deviation.

## CHANGES AFTER VITRECTOMY

Changes in biomechanical measurements before and after vitrectomy are shown in Table 3. There were no significant differences in the non-operated fellow eyes ($p>0.501$ for all variables).

**Table 3. Biomechanical measurements before and after vitrectomy**

| | Before | | After | | Wilcoxon test |
|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | *p*-value |
| IOP [mmHg] | 15.167 | 1.579 | 14.167 | 2.278 | **0.034** |
| bIOP [mmHg] | 14.267 | 1.351 | 13.433 | 2.086 | 0.060 |
| Pachymetry [µm] | 548 | 23 | 548 | 22 | 0.966 |
| A1 Time [ms] | 7.768 | 0.201 | 7.673 | 0.281 | 0.156 |
| A1 Deflection Amp. [mm] | 0.090 | 0.009 | 0.090 | 0.005 | 0.866 |
| A2 Time [ms] | 21.968 | 0.302 | 22.317 | 0.290 | **0.002** |
| A2 Deflection Amp. [mm] | 0.092 | 0.013 | 0.107 | 0.009 | **<0.001** |
| HC Time [ms] | 17.133 | 0.212 | 17.094 | 0.385 | 0.874 |
| HC Deflection Amp. [mm] | 0.818 | 0.057 | 0.890 | 0.127 | **0.005** |
| Max Deflection Time [ms] | 16.774 | 0.325 | 17.026 | 0.505 | **0.009** |
| Max Deflection Amp. [mm] | 0.822 | 0.057 | 0.895 | 0.126 | **0.005** |
| SP-A1 | 118.451 | 20.643 | 110.019 | 14.044 | **0.009** |
| SSI | 1.163 | 0.119 | 1.099 | 0.205 | 0.112 |
| Max. WEM Time [ms] | 22.010 | 0.763 | 22.262 | 0.312 | 0.088 |
| Max. WEM Distance [mm] | 0.325 | 0.076 | 0.257 | 0.077 | **0.020** |

IOP - intraocular pressure; bIOP - biomechanical-corrected; A1 - first applanation; (A2) second applanation; HC - moment of highest concavity; Max - maximum; Amp - amplitude; SP-A1 - stiffness parameter A1; SSI - stress-strain index; WEM - whole eye movement; SD - standard deviation.

## POSTERIOR VITREOUS DETACHMENT

In our sample, 8 eyes had macular PVD preoperatively. Of these, 4 eyes had also papillary PVD (complete PVD). No eye without macular PVD had papillary PVD. Patients with macular PVD were older (58.2 ± 8.5 *vs* 46.8 ± 4.5, *p*=0.003). The reason for vitrectomy was not associated with the presence of PVD (chi-square, *p*=0.371). Table 4 shows a cross-sectional analysis comparing eyes with and without macular PVD. Analysis according to complete PVD was not performed due to the reduced number of eyes. In a subgroup analysis, the whole eye movement decreased non-significantly after vitrectomy in eyes without PVD (difference -0.092 mm, *p*=0.101) but remained similar in eyes with PVD (difference +0.004 mm, *p*=0.282).

**Table 4. Cross-sectional comparison of preoperative biomechanical measurements in eye with and without macular vitreous detachment.**

| | Macular posterior vitreous detachment | | | | |
|---|---|---|---|---|---|
| | No (n=16) | | Yes (n=8) | | *p*-value |
| | Mean | SD | Mean | SD | |
| IOP [mmHg] | 15.000 | 0.632 | 15.500 | 2.673 | 1.000 |
| bIOP [mmHg] | 14.625 | 1.125 | 13.550 | 1.550 | **0.047** |
| Pachymetry [µm] | 535.250 | 15.704 | 574.000 | 9.621 | **<0.001** |
| A1 Time [ms] | 7.736 | 0.101 | 7.832 | 0.321 | 1.000 |
| A1 Deflection Amp. [mm] | 0.095 | 0.003 | 0.080 | 0.010 | **<0.001** |
| A2 Time [ms] | 22.016 | 0.246 | 21.872 | 0.392 | 0.329 |
| A2 Deflection Amp. [mm] | 0.094 | 0.013 | 0.087 | 0.013 | 0.329 |
| HC Deflection Amp. [mm] | 0.839 | 0.047 | 0.776 | 0.052 | 0.329 |
| HC Time [ms] | 17.209 | 0.207 | 16.979 | 0.123 | **0.008** |
| Max Deflection Amp. [ms] | 0.844 | 0.048 | 0.777 | 0.051 | **0.047** |
| Max Deflection Amp. [mm] | 16.591 | 0.107 | 17.141 | 0.304 | **<0.001** |
| SP-A1 | 104.565 | 2.326 | 146.221 | 8.155 | **<0.001** |
| SSI | 1.135 | 0.060 | 1.220 | 0.182 | 0.329 |
| Max. WEM Time [ms] | 22.193 | 0.878 | 21.645 | 0.180 | **0.047** |
| Max. WEM Distance [mm] | 0.328 | 0.094 | 0.320 | 0.001 | **0.047** |

IOP - intraocular pressure; bIOP - biomechanical-corrected; A1 first applanation; (A2) - second applanation; HC - moment of highest concavity; Max - maximum; Amp - amplitude; SP-A1 - stiffness parameter A1; SSI - stress-strain index; WEM - whole eye movement; SD - standard deviation.

## DISCUSSION

The present study is the first *in vivo* assessment of the vitreous contribution to ocular biomechanics. We used a high-speed camera during a corneal air puff to measure the displacement of the posterior segment of the eye before and after surgical removal of the vitreous. We found that after vitreous removal this displacement is smaller, which suggests that the vitreous exerts a centripetal force on the globe. As illustrated in Fig. 1, this force materializes in the opposite direction than the intraocular pressure. Interestingly, the measurements of intraocular pressure were lower after surgery, even for biomechanical-corrected intraocular pressure. The lower IOP alone would produce the opposite effect on WEM, which reinforces a true effect of the vitreous removal in the latter. Being the most voluminous tissue in the eye, it is unsurprising that the vitreous, together with the cornea and the sclera, contributes to ocular biomechanics.[11] In fact, the change in WEM distance was considerably (21% reduction), which suggests that the vitreous' role is significant.

Initially, the histological study of vitreous body used to be hampered by the high amount of water, artefacts during tissue fixation and the precipitation of hyaluronic acid. More recent *postmortem* studies have described the internal vitreous structure: collagen fibers arise from the vitreous base and connect it to the posterior pole.[2] This structure explains our results: the removal of the collagen fibers releases anterior-posterior tension. A study from 1978, conjectured that if collagen was removed from the vitreous, the glycosaminoglycans form a viscous solution; however if hyaluronan was removed, the vitreous would shrink given the elastic proprieties of the collagen,[7] which also relates to our findings.

In eyes with PVD, collagen fibers no longer connect at the posterior end of their coronal path, and they appear to move freely, not able to exert any tensile force. The cross-sectional comparison showed that eyes with macular vitreous detachment have a shorter WEM, even before vitrectomy.

We also observed changes in corneal biomechanics, namely a propensity to softer corneal behavior after surgery. These changes may be determined by the IOP after surgery,

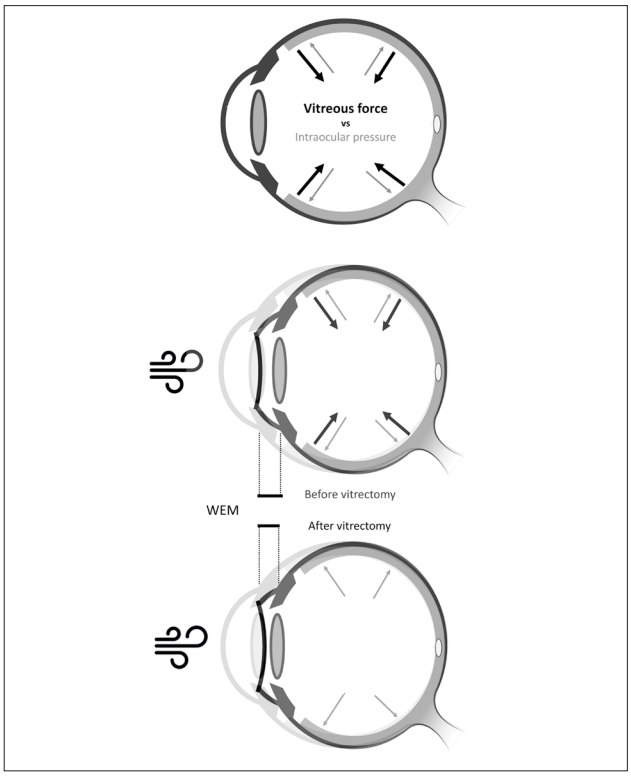


Figure 1. Ilustration of the relation between the vitreous centripetal force and intraocular pressure, together with the resulting whole eye movement (WEM) during the air puff, before and after vitrectomy.

but the measurement of IOP may also be influenced by true biomechanical changes. Stress-strain index (SSI), a second-generation parameter that represents corneal biomechanical behavior independently of IOP and corneal thickness,[12] was non-significantly reduced ($p$=0.112). It remains unclear if corneal biomechanics are really affected after vitreous removal. Still, a possible explanation for a softer corneal behavior after vitrectomy is the absence of hyaluronan, responsible for viscous proprieties, in the empty anterior vitreous cavity. Several studies in animal eyes agree that there are two distinct rheological behaviors of the vitreous: a solid-like phase composed of collagen, and a viscous phase composed of hyaluronan.[8,9] Moreover, the vitreous viscosity is higher near the lens[13] and that same region is the one with lowest density of collagen fibers.[10] Therefore, it is conceivable that the vitreous retains the position of the anterior segment (a consequence hyaluronan viscosity) and, at the same time, it applies traction on the posterior segment (due to its collagen fibers that connect the anterior to posterior poles). Changes corneal behavior were seen preoperatively in eyes with PVD, however pachymetry was significantly higher in these subjects and SSI was unchanged. Therefore, no proper conclusions can be reached regarding corneal biomechanical changes related to PVD.

Some other recent papers measured *in vivo* WEM: Aoki *et al* found a negative correlation between WEM and axial length.[14] This finding is compatible with ours and may be explained by decreased collagen content, vitreous liquefaction and early PVD in myopic eyes.[2,15-17] However, scleral thickness and resistance may be an additional contributive factors for changes in WEM in myopic eyes.[11] We did not contemplate axial length measurement, but the refractive error interval of our sample was small and had no extreme values. Therefore, it is unlikely that axial length was a confounding factor in our study.

Another study, by Vinciguerra *et al*, measured WEM in healthy subjects and observed that WEM increases with age.[18] However, they did not evaluate the presence of PVD. PVD is age-related[19] and this might have been a confounding factor in their study. We found no direct association of WEM and age, considering both the full sample and the subgroup without PVD. Still, vitreous collagen undergoes cross-linking and dehydration with age.[2,15] It is plausible that, until PVD occurs, vitreous aging leads to higher tractional force, and consequently, larger WEM. At the moment of PVD, the tension is released and WEM decreases.

One of the current developments in medicine is moving from static to dynamic examinations. It has ensued in computer tomography and magnetic resonance of the brain and body.[20,21] Optical coherence tomography angiography is a good example of how dynamic and repeated in time evaluation of static images, may reveal previously hidden information.[22] Sequential tomographic imaging of the eye during compression is another step forward in ophthalmological research. There are limitations to this type of measurement of ocular biomechanics, namely its reliance on intra-ocular pressure. Moreover, the type of device used in this study cannot isolate vitreous biomechanics in a single timepoint and its measurements are coarse for such a complex structure. New technologies such as optoacoustic imaging,[23] *in vivo* shear rheometry[24] or dynamic light scattering spectroscopy,[25] may provide further insights.

Another limitation of our study is the small sample size, namely the reduced number of eyes with posterior vitreous detachment, that precludes a subgroup longitudinal analysis according to the posterior vitreous status.

We included subjects submitted to PPV without additional procedures such as cataract surgery, photocoagulation, cryotherapy, or gas tamponade, aiming to isolate the role of the vitreous alone and avoiding extra biases. Additionally, over half of the subjects in our sample had vitreous opacities due to hereditary transthyretin amyloidosis. Mutant TTR deposits and aggregates along the collagen fibers which may influence vitreous mechanical behavior.[26] Still, we found no differences in preoperative measurements of these subjects, when compared to subjects with primary epiretinal membrane.

The clinical importance of these findings is not yet established. In the future, a better understanding of vitreous biomechanics and the ability to measure the tension of its collagen fibers may help to predict the risk of retinal tears and retinal detachment, optimize vitreoretinal surgery, and even improve effective lens position in intraocular lens calculation.

In conclusion, we found that the WEM is reduced after vitrectomy, suggesting that the vitreous exerts a centripetal force on the globe. This effect may be minimized in eyes with posterior vitreous detachment.

## CONTRIBUTORSHIP STATEMENT / DECLARAÇÃO DE CONTRIBUIÇÃO:

All authors fill the criteria of the International Committee of Medical Journal Editors.

## RESPONSABILIDADES ÉTICAS

**Conflitos de Interesse:** Os autores declaram a inexistência de conflitos de interesse na realização do presente trabalho.

**Fontes de Financiamento:** Não existiram fontes externas de financiamento para a realização deste artigo.

**Confidencialidade dos Dados:** Os autores declaram ter seguido os protocolos da sua instituição acerca da publicação dos dados de doentes.

**Proteção de Pessoas e Animais:** Os autores declaram que os procedimentos seguidos estavam de acordo com os regulamentos estabelecidos pelos responsáveis da Comissão de Investigação Clínica e Ética e de acordo com a Declaração de Helsínquia revista em 2013 e da Associação Médica Mundial.

**Proveniência e Revisão por Pares:** Não comissionado; revisão externa por pares.

## ETHICAL DISCLOSURES

**Conflicts of Interest:** The authors have no conflicts of interest to declare.

**Financing Support:** This work has not received any contribution, grant or scholarship

**Confidentiality of Data:** The authors declare that they have followed the protocols of their work center on the publication of data from patients.

**Protection of Human and Animal Subjects:** The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and with those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2013).

**Provenance and Peer Review:** Not commissioned; externally peer reviewed.

## REFERENCES

1. Foulds WS. Is your vitreous really necessary? Eye. 1987;16:641–64.
2. Sebag J. Vitreous and Vision Degrading Myodesopsia. Prog Retin Eye Res. 2020;79:100847. doi: 10.1016/j.preteyeres.2020.100847.
3. Repetto R, Tatone A, Testa A, Colangeli E. Traction on the retina induced by saccadic eye movements in the presence of posterior vitreous detachment. Biomech Model Mechanobiol. 2011;10:191-202. doi: 10.1007/s10237-010-0226-6.
4. Liu X, Wang L, Wang C, Sun G, Liu S, Fan Y. Mechanism of traumatic retinal detachment in blunt impact: a finite element study. J Biomech. 2013;46:1321-7. doi: 10.1016/j.jbiomech.2013.02.006.
5. Sebag J, Balazs EA. Morphology and ultrastructure of human vitreous fibers. Investig. Ophthalmol Vis Sci. 1989;30:1867–71.
6. Bishop PN. Structural macromolecules and supramolecular organisation of the vitreous gel. Prog Retin Eye Res. 2000;19:323-44. doi: 10.1016/s1350-9462(99)00016-6.
7. Comper WD, Laurent TC. Physiological function of connective tissue polysaccharides. Physiol Rev. 1978;58:255-315. doi: 10.1152/physrev.1978.58.1.255.
8. Silva AF, Alves MA, Oliveira MSN. Rheological behaviour of vitreous humour. Rheol Acta. 2017;56:377–86.
9. Sharif-Kashani P, Hubschman JP, Sassoon D, Kavehpour HP. Rheology of the vitreous gel: effects of macromolecule organization on the viscoelastic properties. J Biomech. 2011;44:419-23. doi: 10.1016/j.jbiomech.2010.10.002.
10. Bos KJ, Holmes DF, Meadows RS, Kadler KE, McLeod D, Bishop PN. Collagen fibril organisation in mammalian vitreous by freeze etch/rotary shadowing electron microscopy. Micron. 2001;32:301-6. doi: 10.1016/s0968-4328(00)00035-4.
11. Boote C, Sigal IA, Grytz R, Hua Y, Nguyen TD, Girard MJ. Scleral structure and biomechanics. Prog Retin Eye Res. 2020;74:100773. doi: 10.1016/j.preteyeres.2019.100773.
12. Eliasy A, Chen KJ, Vinciguerra R, Lopes BT, Abass A, Vinciguerra P, et al. Determination of Corneal Biomechanical Behavior in-vivo for Healthy Eyes Using CorVis ST Tonometry: Stress-Strain Index. Front Bioeng Biotechnol. 2019;7:105. doi: 10.3389/fbioe.2019.00105.
13. Bettelheim FA, Zigler JS. Regional mapping of molecular components of human liquid vitreous by dynamic light scattering. Exp. Eye Res. 2004;79:713–8.
14. Aoki S, Murata H, Matsuura M, Fujino Y, Nakakura S, Nakao Y, et al. The effect of air pulse-driven whole eye motion on the association between corneal hysteresis and glaucomatous visual field progression. Sci Rep. 2018;8:2969. doi: 10.1038/s41598-018-21424-8.
15. Berman ER, Michaelson IC. The chemical composition of the human vitreous body as related to age and myopia. Exp Eye Res. 1964;3:9–15.
16. Favre M, Goldmann H. Zur Genese der hinteren Glaskörperabhebung. Ophthalmologica. 1956;132:87–97.
17. Cases O, Obry A, Ben-Yacoub S, Augustin S, Joseph A, Toutirais G, et al. Impaired vitreous composition and retinal pigment epithelium function in the FoxG1::LRP2 myopic mice. Biochim Biophys Acta Mol Basis Dis. 2017;1863:1242-54. doi: 10.1016/j.bbadis.2017.03.022.
18. Vinciguerra R, Elsheikh A, Roberts CJ, Ambrósio R Jr, Kang DS, Lopes BT, et al. Influence of Pachymetry and Intraocular Pressure on Dynamic Corneal Response Parameters in Healthy Patients. J Refract Surg. 2016;32:550-61. doi: 10.3928/1081597X-20160524-01.
19. SS H, JB J. Posterior vitreous detachment: clinical correlations. Ophthalmologica. 2004;218:333–43.
20. Gamper U, Boesiger P, Kozerke S. Compressed sensing in dynamic MRI. Magn Reson Med. 2008;59:365–73. doi: 10.1002/mrm.21477.
21. Cenic A, Nabavi DG, Craen RA, Gelb AW, Lee TY. Dynamic CT measurement of cerebral blood flow: a validation study. AJNR Am J Neuroradiol. 1999;20:63-73.
22. Laíns I, Wang JC, Cui Y, Katz R, Vingopoulos F, Staurenghi G, V et al. Retinal applications of swept source optical coherence tomography (OCT) and optical coherence tomography angiography (OCTA). Prog Retin Eye Res. 2021;84:100951. doi: 10.1016/j.preteyeres.2021.100951.
23. Kalkhoran MA, Vray D. Sparse sampling and reconstruction for an optoacoustic ultrasound volumetric hand-held

probe. Biomed Opt Express. 2019;10:1545-56. doi: 10.1364/BOE.10.001545.
24. Tram NK, Swindle-Reilly KE. Rheological properties and age-related changes of the human vitreous humor. Front Bioeng Biotechnol. 2018;6:1–12.
25. Fankhauser F 2nd. Analysis of diabetic vitreopathy with dynamic light scattering spectroscopy--problems and solutions related to photon correlation. Acta Ophthalmol. 2012;90:e173-8. doi: 10.1111/j.1755-3768.2011.02308.x.
26. Misumi Y, Ando Y, Ueda M, Obayashi K, Jono H, Su Y, et al. Chain reaction of amyloid fibril formation with induction of basement membrane in familial amyloidotic polyneuropathy. J Pathol. 2009;219:481-90. doi: 10.1002/path.2618.

**Corresponding Author/**
**Autor Correspondente:**

**João Heitor Marques**
Serviço de Oftalmologia,
Centro Hospitalar Universitário do Porto
Rua das Laranjeiras 93,
4150-451 Porto, Portugal
joaoheitormarques@gmail.com

ORCID: 0000-0001-6487-7950