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# Comparative analysis of 23-, 25-, and 27-gauge forceps stiffness and related displacement

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**Abstract**

**Purpose:** To test the stiffness and displacement of different vitreous forceps. Physical features and deformation after multiple procedures were also measured.

**Methods:** Eleven different 23-, 25-, and 27-gauge vitreous forceps were studied. The measurements were repeated loading the probe at different distances from the tip: at the top of the tip and 10 and 20 mm from the tip, respectively. For each probe, 10 successive identical bending tests were performed. The total length and the internal and external diameters of each forceps were also measured.

**Results:** A total of 330 successive identical bending tests were performed. No progression in deformation after the repeated measurements was recorded ($p > 0.05$). In each gauge group, displacement differences were detected according to the manufacturing metal properties, the total length, and the thickness of the shaft wall. A minimal adequate model to describes forceps displacements in terms of their significant predictors, such as gauge, model, and load distance from the tip, was created.

**Conclusion:** We provided a precise assessment of the stiffness and displacement of different vitreous forceps to enable surgeons to select the optimal instrument according to the benefits and limitations of each forceps.

**Keywords**

Retina, vitreous, pars plana vitrectomy, retinal detachment, epiretinal membrane

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## Introduction

The surgical techniques of pars plana vitrectomy (PPV) have significantly refined since the first description of the procedure by Machemer in 1971, who used a 17-gauge (G) multifunctional vitreous infusion suction cutter of 1.42 mm in diameter.[1] The conventional three-port 20G vitrectomy, 0.91 mm in diameter, was introduced in 1974 by O'Malley and Heintz,[2] becoming the standard technique for vitreoretinal surgery for over 30 years. Sutureless vitrectomy in vitreoretinal surgery was initially proposed by Chen[3] in 1996, and in 2002, a complete 25G transconjunctival sutureless microincision vitrectomy system, using 0.51 mm diameter microcannulas, was introduced by Fujii et al.[4,5] In 2005, Eckardt[6] developed a 23G system (0.61 mm in diameter), which offered a compromise between the

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20G and 25G systems with improvements in cutter efficiency, rigidity, and manipulation of the globe. After many innovations and advances in microincision vitrectomy techniques,[7] in 2010 Oshima et al.[8] introduced a novel 27G microincision vitrectomy system with an instrument diameter of 0.40 mm. Transconjunctival sutureless Micro Incision Vitrectomy Surgery (MIVS) with 27G, 25G, or 23G offered many advantages over conventional 20G vitrectomy, including faster wound closure and postoperative recovery,[9] shorter operation time,[10] reduced postoperative inflammation[11,12] and astigmatism,[13] and improved patient comfort.[14,15] However, the use of smaller diameter incisions to achieve self-sealing sclerotomies has significantly changed the stiffness of the instrument.[16] In considering the optimal probe diameter for each specific surgical task, the surgeon needs to have information about the unique properties of each system. To our knowledge, only Hubschman et al.,[17] in 2008, reported the flexibility and displacement analysis of the tip of 20, 23 and 25G probes. This study aimed to test the displacement of different 23, 25, and 27G disposable forceps. Physical features, such as the length and diameter and deformation after multiple procedures, were also measured.

## Materials and methods

Eleven vitreous forceps were analyzed. A summary of the probes and their specifications is given in Table 1.

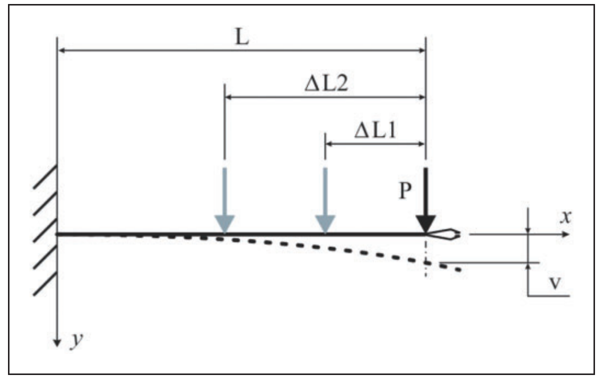


**Figure 1.** Schematic representation of the experiment. In this figure, $P$ is the applied load, $L$ is the total length of the probe, $\Delta L1$ is equal to 10 mm, $\Delta L2$ is equal to 20 mm, and $\nu$ is the displacement. Arrows in light gray represent the two positions where the load was applied, respectively, in $\Delta L1$ and $\Delta L2$.

### *Stiffness measurements*

For each forceps, the displacement was assessed applying a linearly increasing load ($P$ in Figure 1 and equation (1)) using a universal testing machine (Sun 500, Galdabini, Cardano al Campo, VA, Italy). Load increased from 0 Newton (N) up to a maximum value of 0.1N with a crosshead speed of 1 mm/min. The limit of 0.1N was set to avoid the permanent forceps deformation due to the excess elasticity limit of the material. The experiment was repeated loading the probe at different distances from the tip: at the total length of the probe avoiding loading the outer arms of the jaws

**Table 1.** Summary of vitrectomy forceps model analyzed and their specifications.

| Gauge | Denomination | Model | Total length (mm) | Diameter (μm) | |
|---|---|---|---|---|---|
| | | | | Internal | External |
| 23-gauge | 23 A | Grieshaber Revolution DSP, ILM Forceps, Alcon[a] | 29.75 | 0.402 | 0.629 |
| | 23 B | Eckardt End-Gripping, Vitreq[b] | 27.50 | 0.506 | 0.616 |
| | 23 C | ILM Forceps, B&L[c] | 28.00 | 0.373 | 0.532 |
| | 23 D | End-Gripping Forceps, B&L[c] | 28.00 | 0.440 | 0.601 |
| | 23 E | Pinnacle 360°, Fine Tip Eckardt, Synergetics[d] | 28.00 | 0.462 | 0.591 |
| 25-gauge | 25 A | Grieshaber Revolution DSP, ILM Forceps, Alcon[a] | 25.00 | 0.391 | 0.477 |
| | 25 B | Eckardt End-Gripping, Vitreq[b] | 28.00 | 0.434 | 0.507 |
| | 25 C | Asymmetric Peeling Forceps, B&L[c] | 28.00 | 0.349 | 0.497 |
| | 25 D | Pinnacle 360°, Fine Tip Eckardt, Synergetics[d] | 28.25 | 0.490 | 0.387 |
| 27-gauge | 27 A | Grieshaber Revolution DSP, ILM Forceps, Alcon[a] | 25.00 | 0.287 | 0.400 |
| | 27 B | Eckardt End-Gripping, Vitreq[b] | 28.25 | 0.335 | 0.412 |

[a]Alcon, Fort Worth, TX, USA.
[b]Vitreq BV, Vierpolders, The Netherlands.
[c]Bausch&Lomb, Rochester, NY, USA.
[d]Synergetics, O'Fallon, MO, USA.

($L$ in Figure 1), at 10 mm from the tip ($\Delta L1$ in Figure 1), and at 20 mm from the tip ($\Delta L2$ in Figure 1), respectively. Stiffness ($k$) was calculated, knowing the displacement of the tip ($v$) at the maximum load ($P$) using equation (1). Particular attention was given to impress only elastic deformations to the forceps. To this end, after each experiment, the forceps were checked to assess the absence of plastic deformations. To calculate the vitrectomy probe's deformation during repeated movements in the surgical procedures, for each probe 10 successive identical bending tests were performed as follows

$$k = \frac{P}{v} \tag{1}$$

In this equation, $k$ is the stiffness of the forceps, $P$ is the applied load, and $\nu$ is the displacement.

### Length measurements

The total length of the probe ($L$ in Figure 1), from the tip to the insertion in the handpiece, was measured with a digital caliper (Model 500-196-30, Mitutoyo Corp., 965 Corporate Boulevard Aurora, Illinois 60502). All the tests were done successively in the same lab room and at the same temperature.

### External and internal diameter measurements

The inner and outer diameter of the probe was measured by means of calibrated image analyses. The forceps were positioned vertically under a light stereomicroscope (MZ-16, Leica Microsystems, Heerbrugg, Switzerland), and images were acquired at 100× magnification. An image analysis software (Image ProPlus 6.2, Media Cybernetics, Marlow, UK) was used to calculate the forceps diameters. For each forceps, the outer diameter measurement was double-checked with a digital caliper (Model 500-196-30, Mitutoyo Corp., 965 Corporate Boulevard Aurora, Illinois 60502). All the tests were done successively in the same lab room and at the same temperature.

### Statistical analysis

For descriptive analyses, quantitative data were expressed as mean with standard deviation. $p$ values of 0.05 or less were considered statistically significant. Being stiffness ($k$) calculated as the displacement of the tip ($v$) at the maximum load ($P$) according to equation (1), our main measure outcome is the displacement and a statistical model was designed. Data were analyzed and modeled using $R$ language;[18] repeated measures analyses were performed by linear mixed-effects models as implemented in lmer package.[19] Maximum likelihood estimated models selection have been pursued using deviance analysis.[20]

## Results

Ten successive identical bending tests for each probe were performed at the three different distances from the tip. In Table 2, the displacement of the tip of the different probes during each test is reported. No progression in the shaft deformation after the repeated measurements has been recorded ($p > 0.05$). In the 23G group, the forceps 23 B (Eckardt End-Gripping, Vitreq) showed the least displacement (0.582 ± 0.017) when the load was applied at the tip, and the probe 23 A (Grieshaber Revolution DSP, ILM Forceps, Alcon) was the most rigid at 10 and 20 mm from the tip tests, with an average displacement of 0.176 ± 0.004 and 0.032 ± 0.001, respectively. The forceps 25 A (Grieshaber Revolution DSP, ILM Forceps, Alcon)

**Table 2.** Stiffness and displacement of the tested forceps.

| | | At the tip | | 10 mm from the tip | | 20 mm from the tip | |
|---|---|---|---|---|---|---|---|
| Gauge | Denomination | Displacement (mm)[a] | Stiffness (N/mm)[a] | Displacement (mm)[a] | Stiffness (N/mm)[a] | Displacement (mm)[a] | Stiffness (N/mm)[a] |
| 23-gauge | 23 A | 0.654 ± 0.011 | 0.153 ± 0.002 | 0.176 ± 0.004 | 0.568 ± 0.012 | 0.032 ± 0.001 | 3.098 ± 0.071 |
| | 23 B | 0.582 ± 0.017 | 0.172 ± 0.005 | 0.253 ± 0.007 | 0.396 ± 0.011 | 0.050 ± 0.002 | 2.005 ± 0.060 |
| | 23 C | 0.811 ± 0.015 | 0.123 ± 0.002 | 0.284 ± 0.009 | 0.352 ± 0.011 | 0.062 ± 0.004 | 1.608 ± 0.100 |
| | 23 D | 0.834 ± 0.013 | 0.120 ± 0.002 | 0.328 ± 0.006 | 0.305 ± 0.005 | 0.054 ± 0.002 | 1.841 ± 0.072 |
| | 23 E | 0.748 ± 0.011 | 0.134 ± 0.002 | 0.261 ± 0.005 | 0.383 ± 0.008 | 0.046 ± 0.002 | 2.184 ± 0.112 |
| 25-gauge | 25 A | 1.206 ± 0.075 | 0.083 ± 0.005 | 0.217 ± 0.007 | 0.460 ± 0.014 | 0.019 ± 0.002 | 5.467 ± 0.869 |
| | 25 B | 1.284 ± 0.014 | 0.078 ± 0.001 | 0.390 ± 0.005 | 0.257 ± 0.004 | 0.054 ± 0.001 | 1.836 ± 0.044 |
| | 25 C | 1.678 ± 0.031 | 0.060 ± 0.001 | 0.651 ± 0.009 | 0.154 ± 0.002 | 0.113 ± 0.003 | 0.889 ± 0.020 |
| | 25 D | 1.461 ± 0.012 | 0.068 ± 0.001 | 0.486 ± 0.011 | 0.206 ± 0.005 | 0.058 ± 0.004 | 1.743 ± 0.119 |
| 27-gauge | 27 A | 2.223 ± 0.118 | 0.045 ± 0.002 | 0.412 ± 0.033 | 0.244 ± 0.021 | 0.029 ± 0.002 | 3.445 ± 0.320 |
| | 27 B | 2.131 ± 0.023 | 0.047 ± 0.001 | 0.523 ± 0.009 | 0.191 ± 0.003 | 0.081 ± 0.003 | 1.240 ± 0.040 |

[a]Average displacement and stiffness of the tip after 10 successive test (mean ± standard deviation).

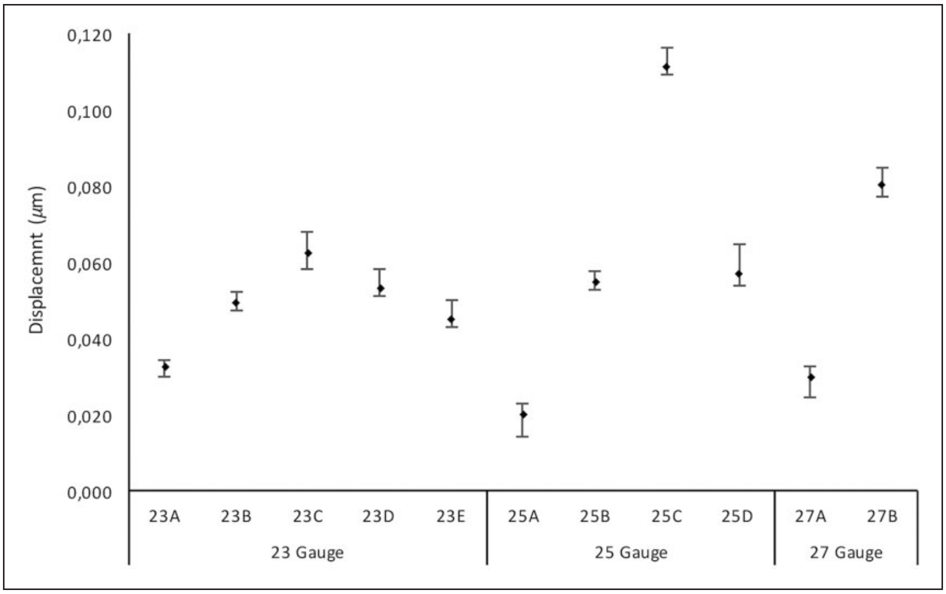


**Figure 2.** Summary distribution of the displacement applying a linearly increasing load 20 mm proximal to the tip in order to evaluate the clinical stiffness of the forceps and simulating the surgeon feeling during vitrectomy. The axis of ordinate shows the mean displacement for each forceps reported in the axis of abscissas. In the different gauge subgroup, the forceps 23 A, 25 A, and 27 A (Grieshaber Revolution DSP, ILM Forceps, Alcon) presented the minor displacement with values of $0.032 \pm 0.001$, $0.019 \pm 0.002$, $0.029 \pm 0.002$, respectively.

showed the least displacement in the 25G group at every distance tested. In the 27G group, the forceps 27 B (Eckardt End-Gripping, Vitreq) was more rigid than the probe 27 A when the load was applied at the tip ($2.131 \pm 0.023$ vs $2.223 \pm 0.118$). The forceps 27 A (Grieshaber Revolution DSP, ILM Forceps, Alcon) presented the least displacement at 10 and 20 mm distance from the tip, with a mean displacement of $0.412 \pm 0.033$ and $0.029 \pm 0.002$, respectively. A graphic representation of the displacement at 20 mm from the tip for each forceps is reported in Figure 2.

The minimal adequate model that describes forceps displacements in terms of their significant predictors, such as gauge, model, and load distance from the tip, are reported in Table 3. The forceps 23C, 23D and 25C (Bausch&Lomb, Rochester, NY, USA) presented a different statistical behavior from the other forceps and were bundled in a single group, named group 3. According to deviance analysis, no interaction between terms was significant. The relations represented in equations (2) and (3) summarized the results, as reported in Figure 3

$$v = -2.651(\pm 0.390) + 0.154\ (\pm 0.016) \times G - 0.059(\pm 0.003) \times d \quad (2)$$

This equation describes the forceps displacement ($v$) in terms of model (*Alcon, Vitreq and Synergetics*), gauge ($G$), and load distance from the tip ($d$).

**Table 3.** The minimal adequate statistical model which describe forceps displacement.

| | Estimated | Standard error | *t*-value |
|---|---|---|---|
| Intercept | −2.651 | 0.390 | −6.802 |
| Group 3 | 0.144 | 0.053 | 2.733 |
| Gauge | 0.154 | 0.016 | 9.795 |
| Distance | −0.059 | 0.003 | −21.705 |

Group 3: Bausch&Lomb (Rochester, NY, USA) forceps model.

$$v = -2.507(\pm 0.443) + 0.154(\pm 0.016) \times G - 0.059(\pm\ 0.003) \times d \quad (3)$$

In this equation, the forceps displacement ($v$) of group 3 (*Bausch&Lomb*) was represented in terms of gauge ($G$) and load distance from the tip ($d$).

To expose the statistical model accurately, the average displacement value related to the different gauges, distances, and forceps models is reported in Table 4. The values in the brackets indicate the sum of the standard error measurements.

## Discussion

The development of the transconjunctival sutureless vitrectomy technique has increased in popularity owing to short operation time, improved patient comfort during the first postoperative week, and faster postoperative visual recovery.[21] The overall surgical

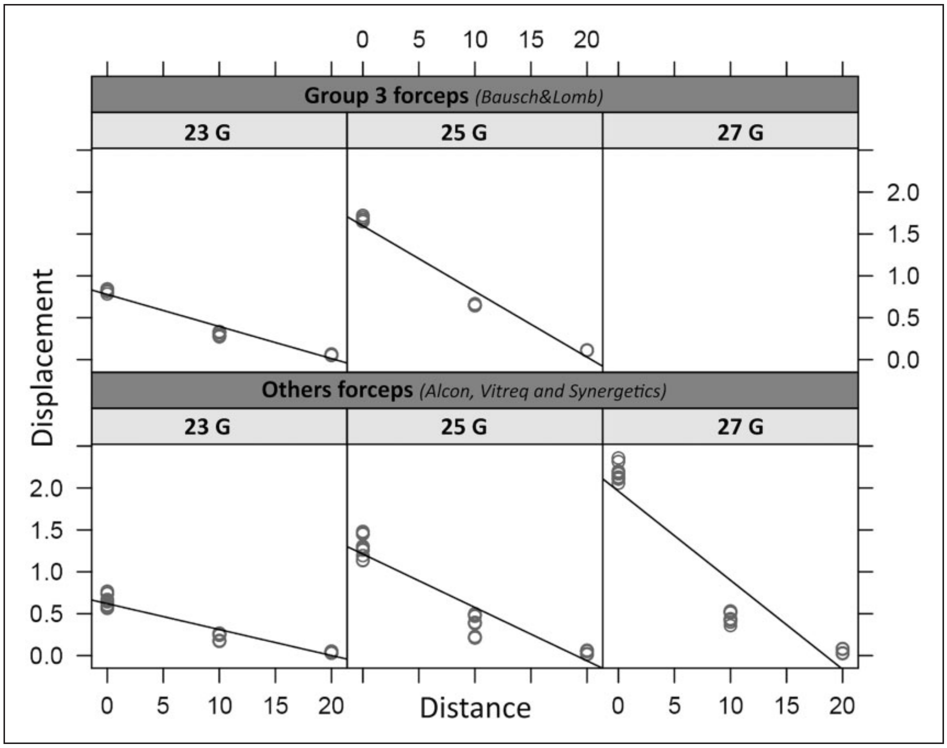


**Figure 3.** Graphical representation of the minimal adequate model which describes the relation between forceps displacement and their analyzed predictors of model, gauge, and load distance from the tip. Group 3 included Bausch&Lomb (Rochester, NY, USA) forceps which presented a different statistical behavior from the other forceps models.

**Table 4.** Average displacement value related to the different forceps models, gauges, and distances.

| Model | Gauge | Distance<br>At the tip | 10 mm from the tip | 20 mm from the tip |
|---|---|---|---|---|
| Alcon, Vitreq Synergetics | 23 | 0.891 (0.409) | 0.301 (0.409) | <0.01 |
| | 25 | 1.199 (0.409) | 0.609 (0.409) | 0.019 (0.409) |
| | 27 | 1.507 (0.409) | 0.917 (0.409) | 0.327 (0.409) |
| Group 3 (Bausch&Lomb) | 23 | 1.305 (0.430) | 0.445 (0.430) | <0.01 |
| | 25 | 1.343 (0.430) | 0.753 (0.430) | 0.163 (0.430) |

time advantage gained by faster port construction with self-sealing sclerotomies was balanced against slower vitreous removal and longer vitrectomy time. Furthermore, the reduction of the instrument caliber results in increased flexibility.[17] Particularly with the thin 27G probe, the displacement of the smaller vitreous instruments may cause a difficult control of movement, especially when using the instruments to rotate the eye for peripheral access and visualization, or to perform different maneuvers such as peripheral vitreous shaving, dissection of proliferative tissue, grasping, and lifting dislocated intraocular lenses.[22] Moreover, paradoxical movements at the tips of thinner forceps can also occur since the stress on the shaft near the proximal end of the forceps can cause a reverse movement of the distal end during attempted rotation of the eye. Some surgeons stabilize the smaller gauge instruments with an extra finger close to the sclerotomy to reduce bending.[23,24]

In order to aid surgeons in selecting the optimal intraocular instruments according to the performance characteristics, in this study we analyzed and compared the stiffness and displacement of different commercially available 23-, 25-, and 27G disposable vitreous forceps. Each forceps was tested at three different distances from the tips. Applying a linearly increasing load at the tip of the shaft and 10 mm proximal to the tip, the global stiffness and the distal displacement of the instrument were tested. To evaluate the clinical stiffness of the forceps and simulating the surgeon feeling during vitrectomy, in the third test a load was applied 20 mm proximal to the tip. As expected, the overall stiffness of the 23G instruments was higher than the 25G group that, in turn, was stiffer than the 27G vitreous forceps (Table 2). These different results are clearly explained by the various external diameters of each G group, as reported in Table 1.

Among the different probes, the forceps A (Grieshaber Revolution DSP, ILM Forceps, Alcon) presented the least displacement at 10 and 20 mm distance from the tip in all G group.

In addition, it is interesting to evidence that in every G group a significant difference in displacement has been detected. In particular, at 20 mm from the tip the displacement, values ranged between 0.032 and 0.062 mm in the 23G, and between 0.019 and 0.113 and between 0.029 and 0.081 mm in the 25G and 27G, respectively. This considerable difference in displacement can be explained considering both the different manufacturing metal properties and the thickness of the shaft wall. Another factor that plays an important role in terms of stiffness and displacement is the total length of the probe. The analysis of this parameter in the 23G group demonstrated a minor difference among the forceps, ranging between 27.50 and 29.75 mm, compared to the 25G and 27G groups, in which the total length of the probe ranged between 25 and 28.25 mm. It is well understood that a longer shaft may dramatically reduce the stiffness of the instruments. Oshima et al.[8] shortened the 27G shaft from 32 to 25 mm, developing a vitreous instrument that had stiffness similar to the 25G probe. Although stiffness is improved by reducing the length, short shafts are not perfectly suited for myopic eyes with long axial length. However, by shortening the shaft, a successfully peripheral vitrectomy using the 27G system in eyes with axial lengths ranging from 22 to 28 mm can be performed.[8]

Initially, 25G vitrectomy was mainly used in macular surgery. As the range of instruments for small G systems increased, surgeons applied 25G and 27G systems to a wider range of surgical indications, including retinal detachments, stages 4 and 5 retinopathy of prematurity, transretinal choroidal biopsy, and posterior capsular opacification in the children.[25–30] In all these cases, a longer operation time, as well as globe manipulation, is required. In our study, to calculate the vitrectomy probe's deformation during repeated movements in the surgical procedures, for each probe 10 successive identical bending tests were performed. Particular attention was given to impress only elastic deformations to the forceps. To this end, after each experiment, the forceps were checked to assess the absence of plastic deformations. No progression in the shaft deformation after the repeated measurements was recorded ($p > 0.005$).

As previously reported, several variables influenced the displacement and stiffness of the probes. In order to consider every variable that may influence these characteristics, a minimal adequate model that describes forceps displacements in terms of their significant predictors, such as gauge, model and load distance from the tip, was developed. According to the different statistical behavior observed testing the forceps 23C, 23D and 25C (Bausch&Lomb, Rochester, NY, USA), a correction coefficient was introduced in the statistical model. In Figure 3 a graphical representation of the minimal adequate model in terms of model, G and applied load distance from the tip was reported. A deviance analysis for the quantitative investigation of the difference between actual and planned behavior, revealed no significant interaction between the terms.

The main limitation of our study is the relatively small number of 27G forceps tested. A larger 27G instruments group is needed to better assess the physical and functional features of this vitrectomy system.

In conclusion, the stiffness and the displacement of the vitreous instruments is a crucial parameter.

The selection of the ideal vitreous instruments for surgery should be based on a balance between probe properties and the surgeon's preference. Forceps with the least displacement when the load was applied at the tip could be more helpful for macular surgery. Conversely, forceps most rigid at 10 and 20 mm from the tip tests could be more effective in a wider range of surgical indications, especially when using the instruments to rotate the eye for peripheral access and visualization or to perform different peripheral maneuvers. The knowledge of these features for the various forceps aid the surgeons in making an educated choice among the different available commercial 23, 25, and 27G disposable forceps to improve patient care.

## Declaration of conflicting interests

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