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**Excimer laser programming for refractive astigmatism or anterior corneal astigmatism
in ocular residual astigmatism (ORA)**

*Programmation au laser excimer de l'astigmatisme réfractif ou de l'astigmatisme cornéen
antérieur en cas d'astigmatisme oculaire résiduel (ORA)*

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02 13 04.

Titre court: Astigmatism programming in ocular residual astigmatism

Conflits d'intérêts: Les auteurs n'ont aucun conflit d'intérêt à déclarer

Le texte n'a pas fait l'objet d'une présentation lors d'un congrès

1 **Excimer laser programming of refractive astigmatism vs. anterior corneal astigmatism**
2 **in the case of ocular residual astigmatism (ORA)**

3 *Programmation au laser excimer de l'astigmatisme réfractif ou de l'astigmatisme cornéen*
4 *antérieur en cas d'astigmatisme oculaire résiduel (ORA)*

5

6 **Abstract**

7 **Purpose:** To determine whether manifest refractive astigmatism (RA) or anterior corneal
8 astigmatism (CA) is the best value for excimer laser programming in cases of ocular residual
9 astigmatism (ORA).

10 **Patients and Methods:** Patients who had undergone LASIK surgery with a disagreement
11 between manifest refractive and corneal cylinder (ocular residual astigmatism ORA) > 0.75 D
12 were included retrospectively in this study. We calculated target induced astigmatism vector
13 (TIA), surgically induced astigmatism vector (SIA), difference vector between the
14 astigmatism correction programmed in the excimer laser and refractive astigmatism (DVRA),
15 difference vector between the astigmatism correction programmed in the excimer laser and
16 corneal astigmatism (DVCA) and difference vector between TIA and SIA (DV), by the
17 Alpins method. Vectorial differences between DV and DVRA, and between DV and DVCA,
18 were then calculated to determine whether RA or CA was closest to the ideal cylinder for
19 laser programming.

20 **Results:** Of a total of 104 eyes undergoing LASIK, 22 eyes of 12 patients (21.1%) had an
21 ORA > 0.75 D and were included. Mean ORA was 0.9 ± 0.2 D and mean postoperative
22 subjective cylinder was 0.45 D. The DV-DVRA difference vector was 0.57 ± 0.2 D, and the
23 DV-DVCA difference vector was 0.86 ± 0.4 D ($P=0.02$). RA was closer than CA to the ideal
24 astigmatism correction.

25 **Conclusion:** In cases of discrepancy between manifest astigmatism and corneal astigmatism,
26 correction of manifest refractive astigmatism seems to give a better refractive result.

27 **Key words:** astigmatism, LASIK, excimer, cornea, ORA, cylinder, refractive surgery

28

29 **Résumé**

30

31 **Objectif:** Déterminer la meilleure valeur à programmer dans le laser excimer entre
32 l'astigmatisme réfractif manifeste (RA) et l'astigmatisme cornéen antérieur (CA) en cas de
33 discordance entre les deux, appelée astigmatisme oculaire résiduel (ORA).

34 **Patients et Méthodes:** Les patients opérés de chirurgie LASIK présentant une discordance
35 entre le cylindre manifeste et le cylindre cornéen (astigmatisme résiduel oculaire ORA) $> 0,75$
36 D ont été inclus rétrospectivement dans cette étude. Le vecteur d'astigmatisme induit cible
37 (TIA), le vecteur d'astigmatisme induit chirurgicalement (SIA), la différence de vecteurs entre
38 l'astigmatisme programmé dans le laser excimer et RA (DVRA), la différence de vecteurs
39 entre l'astigmatisme programmé sur le laser excimer et CA (DVCA) et la différence de
40 vecteurs entre TIA et SIA (DV) ont été calculés par la méthode d'Alpins. Les différences
41 vectorielles entre DV et DVRA, et entre DV et DVCA ont été calculées pour déterminer
42 lequel de RA ou CA donnait la valeur la plus proche du cylindre idéal à programmer sur le
43 laser.

44 **Résultats:** Sur un total de 104 yeux opérés de LASIK, 22 yeux de 12 patients (21,1%) avaient
45 une ORA $> 0,75$ D et ont été inclus. L'ORA moyen était de $0,9 \pm 0,2$ D et le cylindre subjectif
46 postopératoire moyen était de $0,45$ D. La différence de vecteurs entre DV-DVRA était de $0,57$
47 $\pm 0,2$ D et celle entre DV-DVCA était de $0,86 \pm 0,4$ D ($P = 0,02$). RA était plus proche que
48 CA de la correction d'astigmatisme idéale.

49 **Conclusion:** En cas de discordance entre astigmatisme manifeste et astigmatisme cornéen,
50 l'astigmatisme réfractif manifeste semble donner un résultat réfractif supérieur.

51 **Mots-clés :** astigmatisme, LASIK, excimer, cornée, ORA, cylindre, chirurgie réfractive

52 **Introduction**

53 Excimer laser treatments, through photorefractive keratectomy (PRK) and laser *in situ*
54 keratomileusis (LASIK), has proved to be one of the most accurate, safest and most
55 predictable tools in refractive surgery for correcting astigmatism [1-3]. Manifest refractive
56 astigmatism is mostly due to anterior corneal astigmatism. However, discrepancies between
57 refractive astigmatism (RA) and anterior corneal astigmatism (CA) are common and are
58 quantified by a vector difference between RA and CA known as ocular residual astigmatism
59 (ORA) [4]. Several studies have shown that the correction of astigmatism is less predictable
60 in cases of high ORA than in cases of low ORA [5-8]. ORA results from posterior corneal,
61 lenticular, vitreous and retinal astigmatism. Programming for RA is an obvious choice if
62 preoperative RA corresponds to anterior corneal toricity. Indeed, excimer photoablation takes
63 place on the anterior surface of the cornea and is more appropriate for the treatment of
64 anterior corneal astigmatism. However, if RA is greater than CA, total RA correction by
65 photoablation will create a new astigmatism on the cornea, due to corneal aberrations. Some
66 studies have suggested that topographic astigmatism should be included in the treatment of
67 patients with ORA, rather than pure manifest refractive cylinder [8-11].

68

69 In cases of discrepancy between RA and CA, a key question remains to be addressed: what is
70 the best astigmatism value to use when programming the excimer machine, as excimer laser
71 ablation acts solely by reshaping the anterior cornea.

72 The aim of this study was to determine whether RA or CA was closest to the ideal cylinder
73 for laser programming. We retrospectively analyzed refractive results for patients undergoing
74 LASIK with an ORA > 0.75 D by the Alpíns method [12]. We performed a vectorial analysis
75 to compare postoperative refractive outcomes with the gap between planned astigmatism and

76 RA, and with the gap between planned astigmatism and CA, to determine which measurement
77 should be used for planning to obtain the lowest level of residual astigmatism.

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86 **Patients and methods**

87

88 In this retrospective analysis, we reviewed the data for consecutive patients who had
89 undergone LASIK refractive surgery at the Quinze-Vingts National Ophthalmology Hospital,
90 Paris, France, performed by a single surgeon (LT). This study was performed in accordance
91 with the Declaration of Helsinki and patients gave their informed consent for collecting and
92 analyzing their data. Patients treated for hyperopic or myopic astigmatism by LASIK were
93 enrolled. The other inclusion criteria were: no history of ocular surgery or disease, age
94 between 23 and 50 years, no cataract or dry eye disease, manifest sphere between -8.00 and
95 +3.00 D, manifest refractive cylinder between -5.00 and 0,00 D, corrected distance visual
96 acuity (CDVA) of 20/20 or better, a minimum postoperative follow-up of three months, and a
97 difference between preoperative manifest refractive astigmatism and anterior corneal
98 astigmatism > 0.75 D. The patients included had no contraindication for LASIK, such as
99 forme fruste keratoconus, irregular and asymmetric astigmatism, or a calculated corneal
100 residual bed of less than 300 μm after laser ablation.

101

102 **Surgical technique**

103 The same surgeon (LT) performed all surgical interventions. The programming of the excimer
104 laser for astigmatism did not always correspond to RA, with modulation according to CA in
105 some cases. Before procedures, 0.4% topical oxybuprocaine hydrochloride was applied three

106 times to each eye. A corneal flap was created with an Intralase FS60© femtosecond laser
107 (Johnson and Johnson Vision, Jacksonville, Florida, USA). The laser had a pulse frequency of
108 60 kHz, an energy of 0.75 μ J and a pulse duration of between 600 and 800 fs. Line and spot
109 spacings were 8 μ m. Superior hinged flaps were created. The intended flap thickness was 110
110 μ m, and the side-cut angle was 90 degrees. The flap diameter was between 8.5 and 9 mm.
111 Once the flap had been lifted, excimer laser Wavelight© EX500 (Alcon Laboratories, Inc.,
112 Fort Worth, Texas, USA) treatment was performed on the stromal bed, with a 6.0 mm optical
113 zone and 0.5 mm transition zone. The corneal stromal bed was irrigated with balanced normal
114 salt solution before the flap was repositioned. After surgery, the patients were told to instill a
115 combination of dexamethasone and tobramycin drops three times daily for one month.

116

117 **Postoperative evaluation**

118 Clinical results were assessed at a follow-up visit three months after surgery. Postoperative
119 data included measurements of uncorrected distance visual acuity (UDVA) and CDVA, with
120 a Snellen acuity chart at 5 m, and manifest refraction (sphere and cylinder).

121

122 **Vectorial analysis**

123 The vectorial analysis was performed by the Alpins method [12, 13]. The aim of this study
124 was to perform a retrospective analysis of postoperative refractive astigmatism and
125 programmed astigmatism values, to determine whether the use of RA or CA to program the
126 laser would have given the smallest postoperative residual cylinder. The amplitude and axis of
127 ORA was defined with a double-angle vector diagram, as the difference vector between
128 preoperative RA and CA (Fig. 1). The CA value was obtained by corneal topography
129 (Pentacam©, Oculus, Wetzlar, Germany). The target induced astigmatism (TIA) vector
130 corresponds to the preoperative RA with a 90° opposite axis, and the surgically induced

131 astigmatism (SIA) vector is the difference vector between postoperative and preoperative
132 refractive astigmatism values, corresponding to the actual change in astigmatism induced by
133 surgery. The difference vector (DV) is the vectorial difference between TIA and SIA and
134 represents the residual uncorrected astigmatism (Fig. 2). The index of success was calculated
135 by dividing DV by TIA. The programming value of astigmatism (PRA) in the excimer laser
136 was not always the preoperative RA, and was frequently influenced and partially modulated
137 according to CA (Fig. 3). The vectorial difference between PRA and RA on the excimer laser
138 (called DVRA) and the vectorial difference between PRA and CA on the excimer laser (called
139 DVCA) were calculated (Fig. 4). Finally, we assessed vectorial differences between DV and
140 DVRA, and between DV and DVCA (Fig. 5). The lowest value was used to determine
141 whether DVRA or DVCA was closest to the DV actually measured, indicating which of RA
142 and CA was the ideal value for programming purposes. DV measured the error of correction
143 between the target correction and the achieved correction. If this error was closer to the
144 difference between the programmed correction and RA (DVRA) than to that between the
145 programmed correction and CA (DVCA), then RA would be the best value to use for laser
146 programming, making it possible to obtain results closer to the target correction. Conversely,
147 if DV was closer to DVCA, then CA would be more reliable than RA for achieving the target
148 correction. We illustrate this with the example of a patient, to facilitate understanding (Table
149 1).

150

151 **Statistical analysis**

152 Results are presented as the mean \pm standard deviation for continuous variables and as
153 proportions (%) for categorical variables. Difference vectors were compared in Student's *t*
154 test. A *P* value < 0.05 was considered statistically significant. Statistical analyses were
155 performed with Excel 2011 software (Microsoft Corp).

156

157 **Results**

158 Of a total of 104 consecutive eyes undergoing LASIK surgery, 22 eyes from 12 patients
159 (21.1%) had an ORA > 0.75 D and were included in this study. The mean age and sex of the
160 patients, the preoperative refractive sphere and cylinder, preoperative anterior corneal
161 cylinder and preoperative ORA are shown in Table 2.

162

163 Mean preoperative ORA was 0.95 ± 0.28 D, mean preoperative refractive astigmatism was
164 0.96 ± 0.59 D and mean postoperative refractive cylinder was 0.52 ± 0.25 D. Mean DV was
165 0.52 ± 0.3 D and the mean index of success was 0.52, indicating that 48% of the preoperative
166 refractive astigmatism was treated. DVRA was 0.2 ± 0.22 D and DVCA was 0.69 ± 0.23 D
167 ($P<0.05$). Programmed astigmatism was significantly closer to RA than CA. The DV-DVRA
168 difference vector was 0.57 ± 0.2 D and the DV-DVCA difference vector was 0.86 ± 0.44 D
169 ($P=0.02$). RA gave the value closest to the ideal correction of astigmatism. The postoperative
170 results are summarized in Table 3.

171

172 **Discussion**

173 In refractive surgery, ORA, defined as a difference between refractive and anterior corneal
174 astigmatism, is not a rare clinical finding. Residual astigmatism can be attributed to the
175 posterior surface of the cornea and internal optics, such as the lens, vitreous and retina, which
176 are not assessed by usual corneal topography procedures. Many studies have reported a lower
177 efficacy of treatments for astigmatism treatments in such cases than for patients with
178 astigmatism located primarily in the anterior cornea [5-8]. Laser surgery for astigmatism was
179 much more effective when RA was concordant with CA. One of the explanations for this
180 finding is that the location of the treatment is also the site of astigmatism. Indeed, as excimer

181 laser ablation occurs on the anterior cornea, the cylindrical correction is more appropriate and
182 accurate if this site is the principal location of the astigmatism. In cases of discordance
183 between RA and CA due to internal optic-mediated astigmatism, photoablation guided by RA
184 may induce iatrogenic corneal aberrations to compensate the internal astigmatism, thereby
185 decreasing the quality of vision. The optical aberrations induced depend on the type of
186 preoperative astigmatism, with- or against-the-rule. Correcting internal astigmatism by
187 treating astigmatism at another site is not clearly logical. As excimer laser refractive surgery
188 reshapes only the anterior corneal surface, we investigated whether RA or CA was the most
189 appropriate value for the excimer laser programming in cases of discrepancy between these
190 two values. Integrating CA, even only partially, into the programming of the laser for patients
191 with ORA has been suggested by several authors [8-10], and may better respect the location
192 of photoablation treatment.

193

194 This study was original in that we retrospectively analyzed patients undergoing LASIK with
195 an ORA greater than 0.75 D, to determine whether RA or CA gave the best refractive
196 astigmatism results, assuming that the excimer laser is equally precise for all values and axes
197 of astigmatism. We addressed this question, by calculating the DV – DVRA and DV – DVCA
198 difference vectors. The value closest to zero identified the most reliable cylinder for use in
199 programming of the laser to obtain the best postoperative refractive results. We obtained a
200 DV – DVRA difference vector of 0.57 ± 0.2 D, which is significantly lower than the DV –
201 DVCA difference vector of 0.86 ± 0.44 D. DV was thus closer to DVRA than to DVCA,
202 indicating that the magnitude of surgically induced error was very close to the difference
203 between programmed astigmatism and RA. We can therefore deduce that RA is a more
204 appropriate value for the programming of the refractive procedure than CA. A prospective
205 study should be set up to confirm these preliminary results, in which two groups should be

206 compared, one with programming according to RA and the other with programming
207 according to CA, to determine which of these values gives the best postoperative results. The
208 other results of our study are consistent with published findings. Alpíns described an ORA
209 greater than 1.00 D in 34% of eyes [14], and Archer and coworkers reported that 21% of
210 patients had a high ORA (ORA/refractive astigmatism ≥ 1.0) [6]. In our series, patients with
211 an ORA > 0.75 D accounted for 21.1% of the patients undergoing LASIK surgery. The index
212 of success (DV/TIA) in our study was 0.52, a value similar to those reported in other studies.
213 For example, Kugler and coworkers reported an index of success of 0.50 in the high-ORA
214 group [5], Archer and coworkers reported an index of success of 0.37 in the high-ORA group
215 [6] and Qian reported an index of success of 1.75 (indicating overcorrection) [8]. As
216 previously shown in all these articles, efficacy was moderate in our case series, with
217 preoperative astigmatism reduced by only half. Nevertheless, our statistical analyses
218 confirmed that RA gave better postoperative results than CA and should therefore be used to
219 program the excimer machine. The results obtained remain unsatisfactory, as the astigmatism
220 remains only half-corrected. However, attempting total RA correction on the corneal surface,
221 when CA is less than RA, would induce additional astigmatism and new corneal aberrations
222 with deleterious effects on the final results. Logically, reshaping of the anterior cornea with an
223 excimer laser should target only anterior corneal astigmatism, whereas astigmatism due to
224 internal optic defects should be treated by intraocular refractive surgery. Integrating
225 topographic astigmatism into the programming of correction to modulate RA is clearly the
226 path to follow. Arbelaez and coworkers used the vector planning method incorporating
227 corneal and refractive astigmatism [15], but the results obtained were similar to manifest
228 refraction correction.
229

230 Modern topography-guided treatments, such as Wavelight Allegro Contoura© (Alcon
231 Laboratories), convert anterior corneal aberrations to generate an ablation profile [16]. The
232 topography-modified refraction (TMR) protocol used in Wavelight Allegro Contoura©
233 topography-guided treatment modifies the programmed cylindrical refraction to match the
234 value and axis of topographic anterior corneal astigmatism [17,18]. Comparisons between
235 anterior corneal astigmatism correction (in topography-guided ablation) and manifest
236 refractive astigmatism correction have yielded conflicting results. Kanellopoulos reported
237 superior postoperative residual astigmatism outcomes in the TMR group [17]. Wallerstein and
238 coworkers reported results similar to our own, with superior refractive outcomes for clinical
239 manifest refractive astigmatism than for topography-guided treatment based on anterior
240 corneal astigmatism [19]. Another study concluded that there was no significant difference in
241 refractive and visual outcomes between the two types of correction, but that there were fewer
242 higher-order aberrations (HOAs) in topography-guided LASIK [20].

243
244 Topography-guided treatment may be an interesting way forward in the future, for the
245 treatment of astigmatism, particularly in cases of ORA. Further studies are required to
246 determine the exact proportion of CA to incorporate into laser programming for the treatment
247 of astigmatism in topography-guided ablation, to obtain the most suitable compromise
248 between postoperative residual refractive cylinder and corneal aberrations.

249

250

251 **Disclosure of interest:** The authors declare that they have no competing interest.

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310

311

312 **Figure legends**

313 **Figure 1**

314 Vector diagram representing preoperative manifest refractive astigmatism (RA), anterior
315 corneal astigmatism (CA) and the vectorial difference between the preoperative RA and the
316 CA, known as ocular residual astigmatism (ORA).

317 **Figure 2**

318 Vector diagram representing preoperative manifest refractive astigmatism (RA), postoperative
319 refractive astigmatism (PA), the surgically induced astigmatism vector (SIA) corresponding
320 to the difference vector between RA and PA, the target-induced astigmatism vector (TIA),
321 and the difference vector between TIA and SIA (DV).

322 **Figure 3**

323 Vector diagram representing preoperative manifest refractive astigmatism (RA), anterior
324 corneal astigmatism (CA), programming value of astigmatism (PRA) in the excimer laser,
325 target-induced astigmatism vector (TIA), and the difference vector between TIA and SIA
326 (DV).

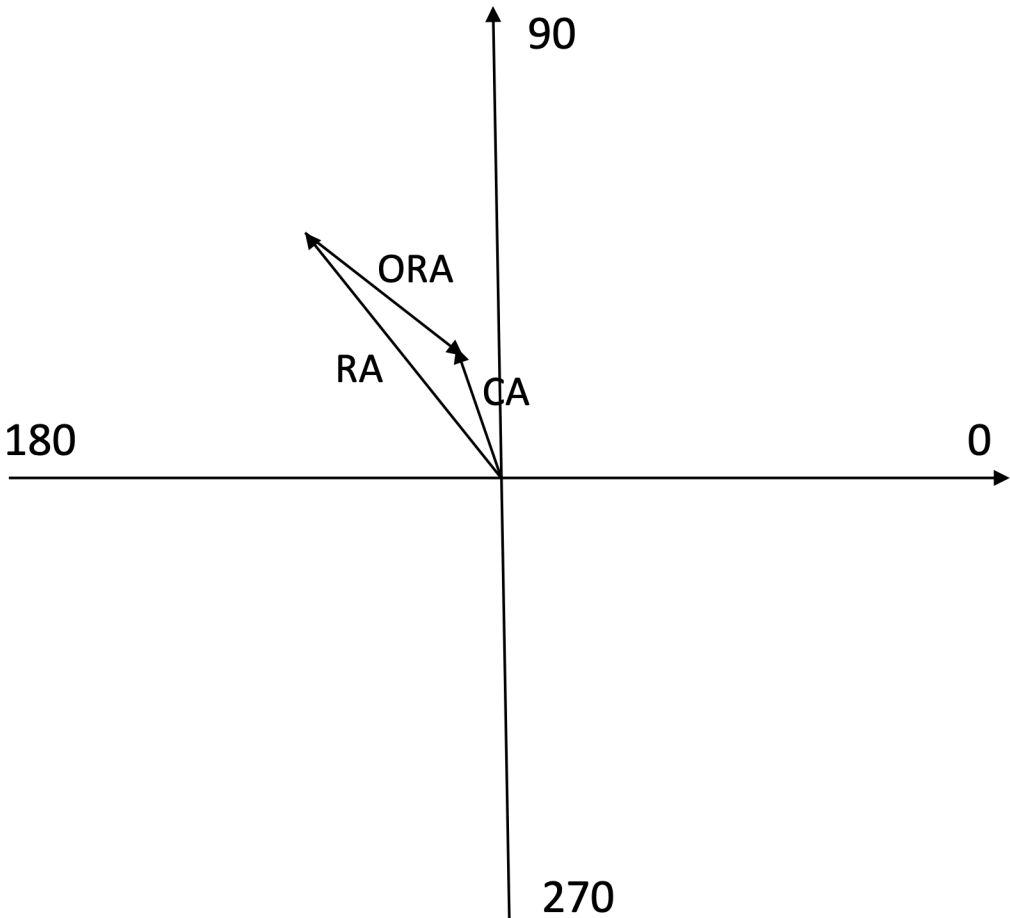
327 **Figure 4**

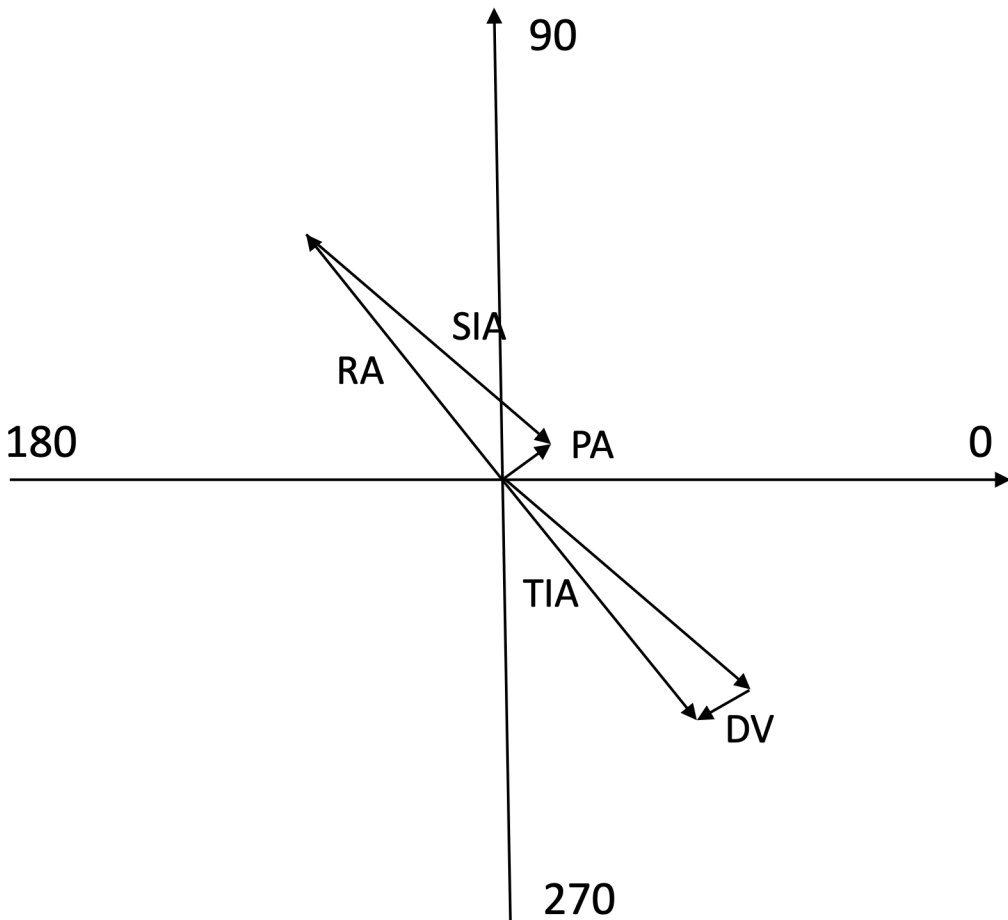
328 Vector diagram representing preoperative manifest refractive astigmatism (RA), anterior
329 corneal astigmatism (CA), programming value of astigmatism (PRA) in the excimer laser,
330 target-induced astigmatism vector (TIA), and the difference vector between TIA and SIA
331 (DV). The vectorial difference between PRA and RA in the excimer laser (called DVRA) and
332 the vectorial difference between PRA and CA in the excimer laser (called DVCA) were
333 calculated.

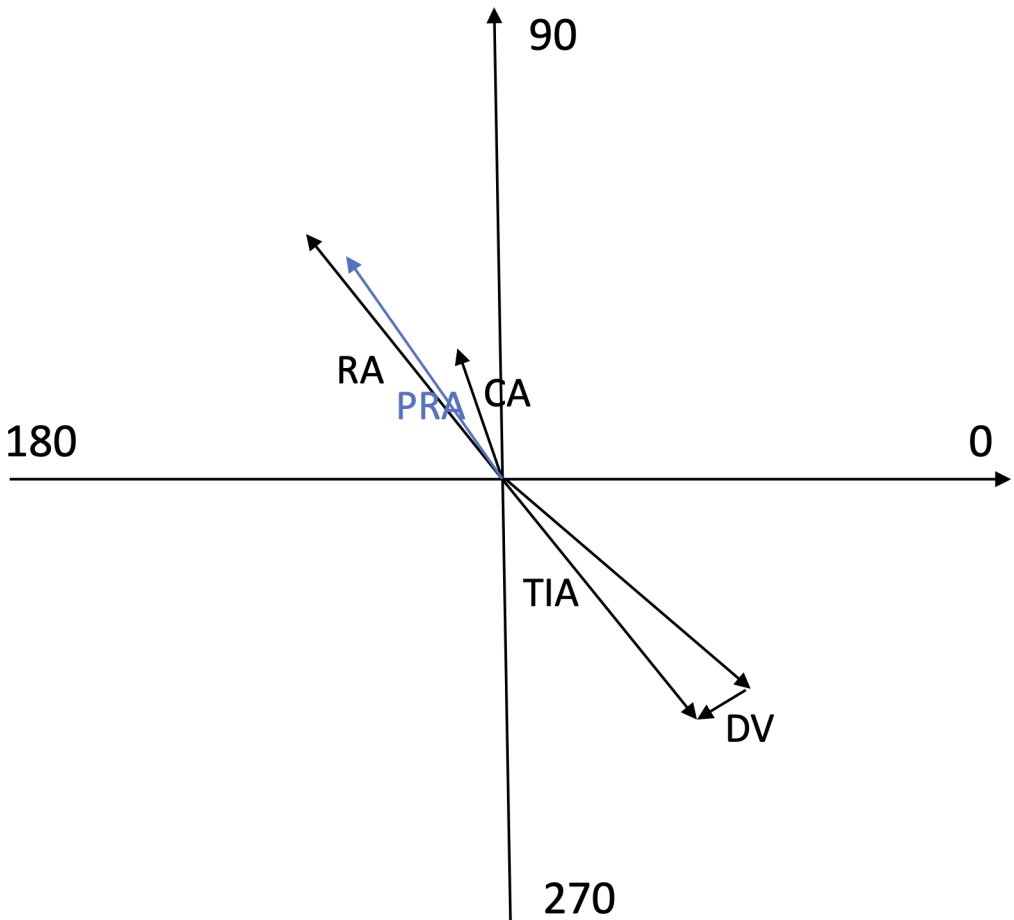
334 **Figure 5**

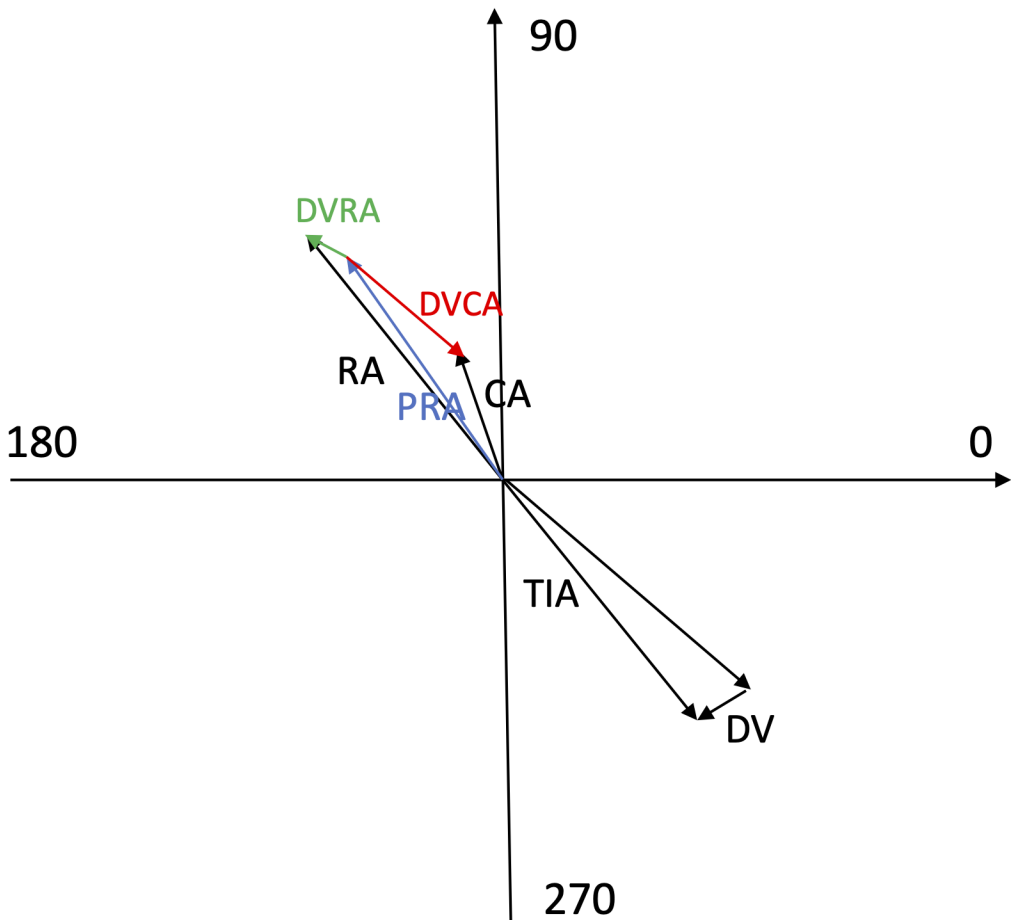
335 Vector diagram representing preoperative manifest refractive astigmatism (RA), anterior
336 corneal astigmatism (CA), programming value of astigmatism (PRA) in the excimer laser,

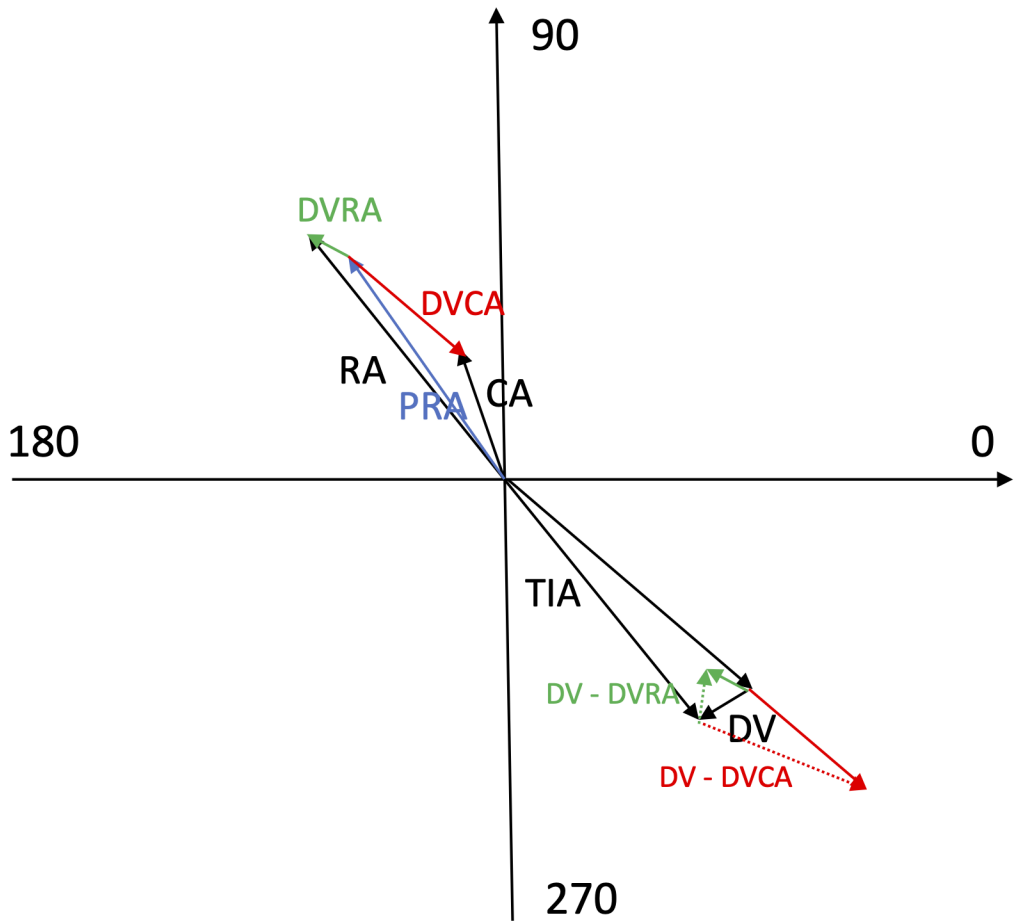
337 target-induced astigmatism vector (TIA), the difference vector between TIA and SIA (DV),
338 the difference vector between PRA and RA in the excimer laser (called DVRA) and the
339 difference vector between PRA and CA in the excimer laser (called DVCA).
340 The DV – DVRA, and DV – DVCA difference vectors were calculated. The lowest difference
341 vector was used to determine whether RA or CA was the closest to the measured DV, i.e. the
342 ideal programming value.











Preoperative manifest refractive astigmatism RA: (-1.75) 115°	Ocular residual astigmatism ORA= RA – CA = (+1.47) 107°
Preoperative anterior corneal astigmatism CA: (-0.50) 140°	
TIA = (+1.75) 115° Programmed astigmatism (PRA): (-1.50) 115°	
Postoperative manifest refractive astigmatism: (-0.25) 0° Postoperative anterior corneal astigmatism: (-0.50) 10° SIA = (+1.90) 112°	
DV = TIA – SIA = (+0.24) 87° DVRA = PRA – RA = (+0.25) 25° DVCA = PRA – CA = (+1.23) 105°	
DV – DVRA = (+0.43) 11° DV – DVCA = (+1.04) 109° DV – DVRA < DV – DVCA	

Table 1: Example of the calculation of difference vectors for one patient

In this example, DV – DVRA is lower than DV – DVCA, so DVRA is closer to DV than DVCA. We can deduce that, for this patient, RA was a more reliable value than CA for excimer laser programming.

TIA: Target induced astigmatism; *SIA*: Surgically induced astigmatism; *DV*: Difference vector between TIA and SIA; *DVRA*: Difference vector between programmed astigmatism (PRA) in the excimer laser and refractive astigmatism (RA); *DVCA*: Difference vector between programmed astigmatism (PRA) in the excimer laser and anterior corneal astigmatism (CA)

Eyes / patients (<i>n</i>)	22 / 12
Female/Male (%)	33 / 67
Mean age (y) ± SD	32 ± 7.4
Mean preoperative sphere (D) ± SD	-1.72 ± 1.65
Mean preoperative refractive cylinder (D) ± SD	0.96 ± 0.78
Mean preoperative anterior corneal cylinder (D) ± SD	1.06 ± 0.38
Mean ORA (D) ± SD	0.95 ± 0.28

Table 2: Patient demographics and ocular characteristics at inclusion

ORA= Ocular residual astigmatism

Mean postoperative refractive cylinder (D) \pm SD	0.52 \pm 0.25
Mean TIA (D) \pm SD	0.96 \pm 0.78
Mean SIA (D) \pm SD	0.87 \pm 0.69
Mean DV (D) \pm SD	0.52 \pm 0.3
Mean index of success	0.52
DVRA (D) \pm SD	0.2 \pm 0.22
DVCA (D) \pm SD	0.69 \pm 0.23 ($P < 0.05$)*
DV – DVRA (D) \pm SD	0.57 \pm 0.2
DV – DVCA (D) \pm SD	0.86 \pm 0.44 ($P = 0.02$)¥

Table 3 Postoperative results

TIA: Target induced astigmatism; SIA: Surgically induced astigmatism; DV: Difference vector between TIA and SIA; DVRA: difference vector between programmed astigmatism in the excimer laser and refractive astigmatism (RA); DVCA: difference vector between programmed astigmatism in the excimer laser and anterior corneal astigmatism (CA)

*significantly different from DVRA

¥ significantly different from DV-DVRA

Student's t test.