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Discordance between Anterior Segment Anatomy and Axial Length in Cataract Surgery Candidates in France

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Keywords
Ophthalmology · Ocular biometry · Cataract · Myopia

Abstract
Introduction: The aims of this study were to study ocular biometric data and their association with age and sex in a population of cataract surgery candidates and to assess the proportion of inhomogeneous eyes and the ratio anterior segment (AS) to axial length (AL). Multicentric cross-sectional analysis was conducted between April 2008 and May 2021 in public and private ophthalmic institutions in Montpellier, France. Individuals ≥40 years old who underwent ocular biometry before cataract surgery were included. ***Methods:*** Right phakic eyes were included. Ocular biometrics were measured by using the Lenstar LS900 device. We defined AS as anterior chamber depth (ACD) plus lens thickness (LT) and calculated the ratio of AS to AL. We defined inhomogeneous eyes as those with deep AS (≥4th quartile) and short AL (≤1st quartile) (AS+) or with short AS and high AL (AL+). ***Results:*** We included 11,650 individuals (11,650 eyes) (mean [SD] age 71.64 [10.50] years; 54.51% women). Older age was associated with shorter AL ($p < 0.01$), shallower ACD ($p < 0.01$), thinner central corneal thickness ($p < 0.01$), and larger LT ($p < 0.001$). Women had shorter AL, shallower ACD, and thinner central corneal thickness than men ($p < 0.001$). In total, 778 (6.68%) eyes were inhomogeneous (3.22% AS+ and 3.46% AL+), for a mean (SD) AS/AL ratio of 0.36 (0.01) and 0.28 (0.01), respectively, as compared with 0.32 (0.02) for homogeneous eyes ($p < 0.001$). ***Conclusion:*** The AS/AL ratio could be useful to screen inhomogeneous eyes before cataract surgery and justify the use of new generation formulas in these eyes to avoid the risk of refractive error.

Introduction

The incidence of cataract surgery is increasing in industrialized countries [1]. It is now considered a refractive procedure with high postoperative expectations. In 2007,

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for intraocular lens (IOL) power calculation, Olsen et al. found 42% error in incorrect estimation of postoperative anterior chamber depth (ACD), 36% in axial length (AL), and 22% in mean keratometry (K) measurements [2]. In 2008, Norrby et al. estimated that 35% of the IOL power calculation error was caused by an effective lens position (ELP) prediction error [3]. Because the precision of optical biometrics using interferometry has greatly increased (12-mm resolution for AL), the postoperative error caused by measurement errors is minor [4, 5].

Third-generation IOL power calculation formulas (SRK/T, Holladay 1, Hoffer Q) consider AL and mean K data [6–8]. The ELP is estimated by equations based on AL and mean K data and depends on the IOL type, with some prediction error in cases of discordance between AL and preoperative ACD [9].

Newer formulas consider the anterior segment (AS) anatomy to better predict the ELP. The Haigis formula estimates ELP from the AL and ACD [10, 11]. The Olsen, Holladay 2, and Barrett Universal II formulas include features such as ACD and lens thickness (LT) to balance the variability in AS anatomy and discordance between AL and preoperative ACD [12–14].

We studied ocular biometrics data and their association with age and sex in a population of cataract surgery candidates. We also assessed the proportion of inhomogeneous eyes (discordance between AL and AS anatomy) and ratio of AS to AL in the different groups. The ratio of AS to AL could be a screening parameter for eyes at risk of refractive error with cataract surgery.

Methods

Study Design

The present study was a retrospective study of patients who underwent ocular biometry from April 2008 to May 2021 in four ophthalmology centers, including one public center, Gui de Chauliac University Hospital, Montpellier, and three private centers: Montpellier, Montferrier, and Saint-Jean de Védas ophthalmology centers. The study followed the principles of the Declaration of Helsinki and was approved by the Ethics Committee of Gui de Chauliac University Hospital Center, Montpellier (Institutional Review Board no. 202100898).

Study Population

Inclusion criteria were ocular biometrics assessment before cataract surgery and age ≥40 years. Exclusion criteria were incomplete examination or previous cataract surgery.

Biometrics Measurements

Ocular biometrics data were recorded by noncontact optical low-coherence reflectometry by using the Lenstar LS900 device (Haag-Streit, Koeniz, Switzerland). The following measurements were recorded for each patient: AL (in millimeters), defined as the axial distance between the anterior corneal surface and the internal limiting membrane of the retina; ACD (in millimeters), defined as the axial distance between the anterior surface of the cornea and the anterior surface of the lens; central corneal thickness (CCT; in micrometers), defined as the axial distance between the anterior surface of the central cornea and the posterior surface of the central cornea; and LT (in millimeters), defined as the axial distance between the anterior surface of the lens and the posterior surface of the lens. We calculated the AS as ACD plus LT and the ratio of AS to AL to define the proportion of "usual eyes."

We defined high myopia as an AL ≥26 mm. We defined birth periods (before 1940, 1940 to 1949, 1950 to 1959, after 1960) to analyze the cohort effect in our sample.

We defined inhomogeneous eyes in two groups: AS+ eyes with deep AS (≥4th quartile [7.92 mm]) and short AL (≤1st quartile [22.91 mm]) and AL+ eyes with short AS (≤1st quartile [7.42 mm]) and high AL (≥4th quartile [24.42 mm]). Values between the 1st and 4th quartiles were considered homogeneous.

Statistical Analysis

Because of a high correlation between the two eyes ($R = 0.9$), only data for the right eyes are presented. Descriptive statistics (mean [SD] and number [%]) were used to report demographic and ocular biometrics variables. The normality of data was tested with the Kolmogorov-Smirnov test. AL distributions were positively skewed and peaked, with a Kurtosis of 3.9. Quantitative variables were analyzed by Student's t test and categorical variables by χ^2 or Fisher test depending on the sample size. The correlation between ocular biometrics variables and age was assessed with the Spearman correlation test. The correlation among ocular biometrics variables was assessed with the Pearson correlation test. Analysis of covariance was used to test the association between AL and age (age considered as categorical variable) adjusted on year of birth. Statistical significance was set at $p < 0.05$. SAS Enterprise Guide 7.1 was used for analysis.

Results

Ocular biometrics data were measured in 15,532 individuals; 3,552 had incomplete data and 330 were pseudophakic and thus excluded from the analysis. Finally, 11,650 right eyes of 11,650 patients were analyzed (online suppl. Table 1; for all online suppl. material, see www.karger.com/doi/10.1159/000526281).

Biometric Characteristics

A total of 6,350 (54.51%) individuals were women (Table 1). The mean (SD) age was 71.64 (10.50) years (range 40–101). Mean values for AL were 23.80 (1.42) mm (range 18.92–33.76), ACD 3.17 (0.40) mm (range 2.02–5.83), LT 4.50 (0.43) mm (range 2.59–6.12), AS 7.67 (0.39) mm (range 5.56–11.46), CCT 539.72 (37.52) μm (range 320–779), and AS/AL ratio 0.32 (0.02)

Table 1. Demographic characteristics and ocular biometrics in study participants (n = 11,650)

Variables	Total	Median (IQR)	Minimum	Maximum
Women, *n* (%)	6,350 (54.51)			
Age, mean (SD), years	71.64 (10.50)	73 (66–79)	40	101
Date of birth, *n* (%)				
<1940	3,013 (25.86)			
1940–1949	4,666 (40.05)			
1950–1959	2,577 (22.12)			
≥1960	1,394 (11.97)			
AL, mean (SD), mm	23.80 (1.42)	23.58 (22.91–24.42)	18.92	33.76
LT, mean (SD), mm	4.50 (0.43)	4.50 (4.21–4.80)	2.59	6.12
ACD, mean (SD), mm	3.17 (0.40)	3.16 (2.90–3.44)	2.02	5.83
AS, mean (SD), mm	7.67 (0.39)	7.67 (7.42–7.92)	5.56	11.46
CCT, mean (SD), μm	539.72 (37.52)	539 (515–564)	320	779
AS/AL ratio, mean (SD)	0.32 (0.02)			
High myopia, *n* (%)	825 (7.08)			

AL, axial length; LT, lens thickness; ACD, anterior chamber depth; AS, anterior segment; CCT, central corneal thickness; IQR, interquartile range.

(range 0.22–0.47). The prevalence of high myopia was 7.08% (n = 825). AL was positively correlated with AS (R = 0.29, $p < 0.001$) (Fig. 1).

Evolution with Age

Pearson correlation analysis revealed a significant correlation of older age with shorter AL ($R = -0.20$, $p < 0.01$), shallower ACD ($R = -0.23$, $p < 0.01$), thinner CCT ($R = -0.06$, $p < 0.01$), and larger LT ($R = 0.36$, $p < 0.001$) (Fig. 2). After adjustment for age on date of birth, analysis of covariance revealed a significant relation between AL and year of birth ($p = 0.001$).

Distribution of Homogeneous and Inhomogeneous Eyes

Table 2 shows the distribution of homogeneous and inhomogeneous eyes. The AS+ group included 375 (3.22%) eyes and the AL+ group 403 (3.46%) eyes. The other 10,872 eyes were considered homogeneous. The AL+ and AS+ groups were younger and older than the homogeneous eye group (mean age 64.8, 76.8, and 71.7 years, respectively) (Table 3). All biometrics data except CCT ($p = 0.33$) differed among the three groups ($p < 0.001$). The largest difference was for LT (1.0 mm) between the AS+ and AL+ groups. The mean (SD) AS/AL ratio was 0.32 (0.02) for homogeneous eyes and was 0.28 (0.01) and 0.36 (0.01) in the AL+ and AS+ groups ($p < 0.001$).

Comparison by Sex

As compared with men, women were significantly older (72.01 vs. 71.20 years, $p = 0.003$) and had shorter AL (23.59 vs. 24.06 mm), shallower ACD (3.12 vs. 3.23 mm), lower AS (7.61 vs. 7.74 mm), and thinner CCT (538 vs. 541 μm) ($p < 0.001$) (Table 4). LT did not significantly differ between men and women ($p = 0.1$).

Discussion

This is the first study of a large population of cataract surgery candidates in a French population considered Caucasian. These data represent normative biometrics values for the French population who are candidates for cataract surgery. Age and sex were significantly associated with all biometrics indices assessed in this study.

Comparison of Mean Values

The mean (SD) AL in our study was 23.80 (1.42) mm. Our results were similar to previous findings among Caucasian populations: 23.32 mm, 23.40 mm, 23.43 mm, 23.44 mm, 23.46 mm, 23.65 mm, 23.87 mm, 23.96 mm, 24.26 mm, and 24.30 mm [15–24]. The most recent studies reported the highest AL values perhaps because of the increase in myopia in younger generations. Thus, the AL standard may need to be redefined in the coming years.

The mean (SD) ACD in our study was 3.17 (0.40) mm, which was within the range of Caucasian study findings: 2.96 mm, 3.11 mm, 3.17 mm, 3.24 mm, 3.25 mm, 3.28 mm, and 3.29 mm. Here also the ACD seemed to increase in the most recent studies [15, 17–19, 21–23].

Concerning LT, most studies used contact applanation ultrasonography or the Lenstar device because the IOLMaster 500 device does not measure LT. Our mean

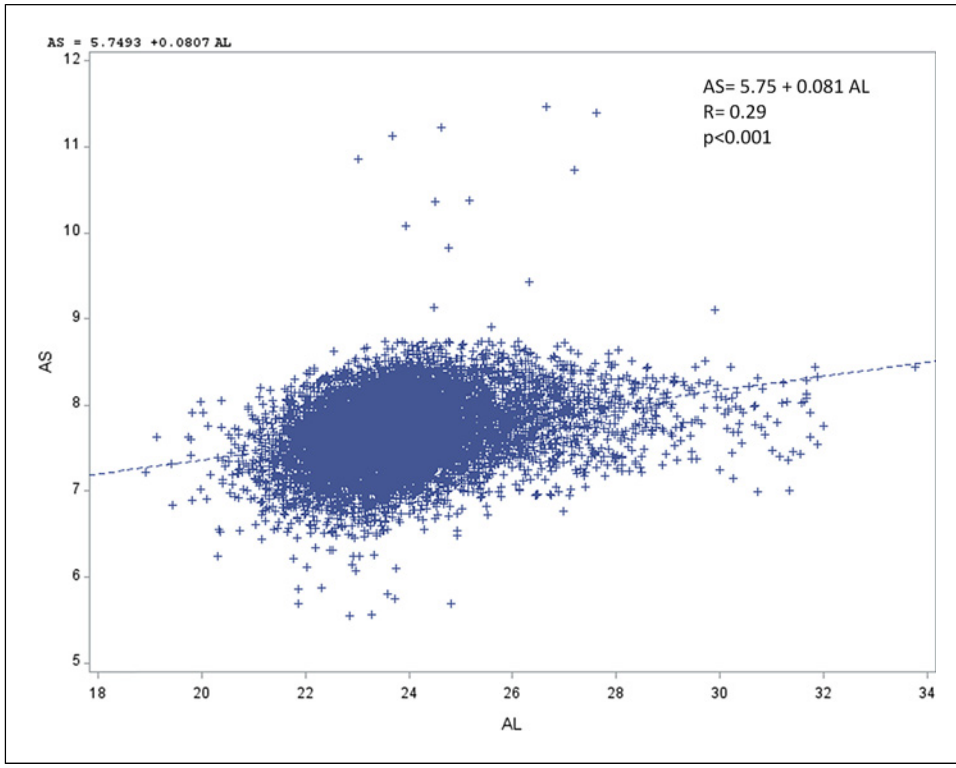

Fig. 1. Distribution of axial length (AL) according to anterior segment (AS) anatomy.

(SD) LT was 4.50 (0.43) mm, which was thinner than in most other studies: 4.32 mm, 4.52 mm, 4.63 mm with US, 4.65 mm, and 4.93 mm with ultrasonography [19, 21, 23, 25, 26].

The IOLMaster 500 device also does not measure CCT. The mean (SD) CCT in our study was 539.72 (37.52) μm, the thinnest value among Caucasian populations free of glaucoma: 544 μm, 547 μm, 549 μm, 550 μm, and 564 μm [23, 27–30].

Evolution of the Eye with Age

The growth of the eye during childhood is a known phenomenon that no longer needs to be demonstrated. However, studies have had contradictory results regarding the eye's behavior in adulthood and during aging. Several Caucasian and Asian studies observed a decrease in AL with age [15, 18, 19, 24, 25, 31]. In 1980, Hoffer noted that people with myopia were younger than average and those with hypermetropia were older than average [20]. We do not know if there is a generational effect in the decrease in AL or if there is an intrinsic shrinkage of the globe with age. Similar to our study, most studies found a negative correlation between ACD and age [15, 17, 19, 32]. ACD decreases with age, which is largely explained by the increase in the size of cataractous lenses [26]. Most studies confirmed that LT increases with age, associated with the appearance of cataracts [19, 22, 25]. Ferreira et al. [21] found no correlation between age and AL, ACD, and LT. Similar to our study, Galgauskas et al. [27] and Weizer et al. [33] found that CCT decreased with age. Shildkrot et al. [29] did not find a correlation of CCT with age [27, 29, 33].

Proportion of Inhomogeneous Eyes

We found a positive correlation between AL and AS. For Hoffmann et al. [17] except for very short and very long eyes, AL was correlated with ACD. We defined a threshold AS/AL ratio as the "homogeneous" anatomical proportions of a standard eye. We used a ratio of 0.32, so the AS of a usual eye represents 32% of its total AL. For 6.68% of inhomogeneous eyes, the AS/AL ratio differed from that in the general population. This is an important point because eyes that do not follow the general law can be a source of refractive error in calculating implant parameters before cataract surgery. In addition, currently, the largest error factor is the ELP, which could be affected by LT [3, 9, 12]. LT was the most variable factor in our population of inhomogeneous eyes.

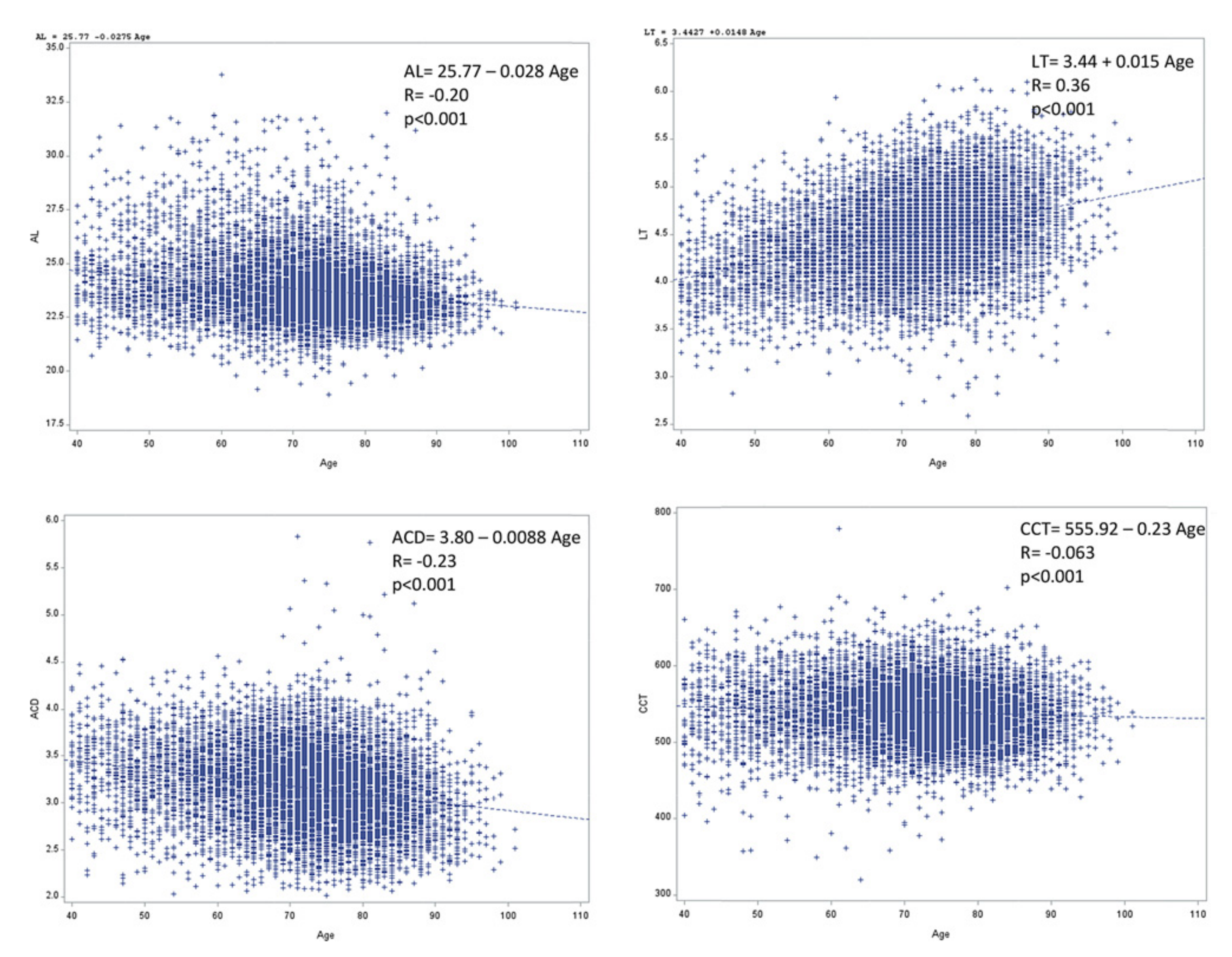

Fig. 2. Distribution of ocular biometrics variables by age.

Table 2. Distribution of homogeneous and inhomogeneous eyes (inhomogeneous eyes in italics)

	AL <22.91 mm	AL 22.91–24.42 mm	AL >24.42 mm
AS <7.42 mm, *n* (%)	1,094 (9.39)	1,419 (12.18)	*403 (3.46)*
AS 7.42–7.92 mm, *n* (%)	1,404 (12.05)	3,008 (25.82)	1,372 (11.78)
AS >7.92 mm, *n* (%)	*375 (3.22)*	1,416 (12.15)	1,159 (9.95)

Data are *n* (%). AS, anterior segment; AL, axial length.

Comparison of Values by Sex

Most studies have found, as we have, that men have greater AL and deeper ACD than do women [15, 17, 19, 21, 24]. The differences in LT between men and women are controversial. In contrast to Ferreira et al. [21] and Jivrajka et al. [19] we did not find any sex difference in LT [19, 21]. However, Shufelt et al. [31] and Hashemi et al. [34] found a thicker LT for men than women [31, 34]. The results of other studies are controversial for CCT. Some found that men had a thicker CCT than women and others found no difference [27, 29, 35]. The evolution of the biometrics data with respect to age for

Table 3. Biometrics characteristics of homogeneous and inhomogeneous eyes

Variable	Homogeneous n = 10,872 (93.32%)	AL + group n = 403 (3.46%)	AS + group n = 375 (3.22%)	p value[a]
Age, years	71.72 (10.36)	64.81 (11.84)	76.83 (9.03)	<0.001
AL, mm	23.79 (1.39)	25.50 (1.24)	22.45 (0.41)	<0.001
LT, mm	4.50 (0.41)	4.02 (0.33)	5.02 (0.34)	<0.001
ACD, mm	3.17 (0.41)	3.21 (0.31)	3.06 (0.34)	<0.001
AS, mm	7.67 (0.39)	7.23 (0.18)	8.08 (0.13)	<0.001
CCT, μm	539 (37)	537 (42)	540 (38)	0.33
AS/AL ratio	0.32 (0.02)	0.28 (0.01)	0.36 (0.01)	<0.001

Data are mean (SD). AS+ group: deep AS (≥4th quartile [7.92 mm]) and short AL (≤1st quartile [22.91 mm]). AL+ group: short AS (≤1st quartile [7.42 mm]) and high AL (≥4th quartile [24.42 mm]). AL, axial length; LT, lens thickness; ACD, anterior chamber depth; AS, anterior segment; CCT, central corneal thickness. [a]Comparing all three groups.

Table 4. Biometrics characteristics by sex

Variable	Women n = 6,350	Men n = 5,300	p value
Age, years	72.01 (10.32)	71.20 (10.69)	0.003
AL, mm	23.59 (1.45)	24.06 (1.33)	<0.0001
LT, mm	4.49 (0.42)	4.51 (0.45)	0.1
ACD, mm	3.12 (0.39)	3.23 (0.41)	<0.0001
AS, mm	7.61 (0.38)	7.74 (0.39)	<0.0001
CCT, μm	538 (36)	541 (38)	<0.0001

Data are mean (SD). AL, axial length; LT, lens thickness; ACD, anterior chamber depth; AS, anterior segment; CCT, central corneal thickness.

men and women was the same as in the overall sample, which suggests that the factors have the same physiological behavior.

Strengths and Limitations

The strengths are the large sample size that allowed us to highlight anatomical differences between groups. The ease of data acquisition with the Lenstar device reduced measurement bias. The multicentric character of our population recruited in public and private centers limited the selection bias.

The limitations are the absence of refraction and K data. We studied a cataract population, which may be different from the general population. We did not have demographic data such as level of education, physical characteristics, or place of residence. Also, we did not know the medical and surgical history of the included individuals or the proportion of traumatic cataracts.

Conclusions and Perspectives

The present study presents normative ocular biometry data for a large European population. Values for all biometric variables changed with age. A longitudinal study is needed to confirm our results, particularly the decrease in AL with age. The improvement in anatomical knowledge will allow us to better understand the physiology of the eye. With the study of inhomogeneous eyes, we also may be able to further improve the IOL power calculation formulas to limit postoperative refractive errors. The AS/AL ratio could be used to screen eyes at risk of postoperative refractive errors. Here again, further studies are needed to investigate the association of AS/AL ratio and postoperative refractive errors.

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Statement of Ethics

Patients were informed for the treatment of medical data by a clear information note. Written informed consent was obtained from the patient for participation in this study. We obtained the authorization of the Montpellier University Hospital Institutional Review Board (no. 202100898), and the study was consistent with the reference methodology MR_003.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Didier Hoa, Chloé Chamard, and Vincent Daien: conceived the original idea; Didier Hoa, Florent Verhaeghe, Jérôme

Jacques, Max Villain, and Vincent Daien: gave data; Marilou Isidore and Chloé Chamard: wrote the manuscript with support from Didier Hoa, Vincent Daien, and Max Villain. All authors discussed the results and contributed to the final manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in this article and its online supplementary material. Further inquiries can be directed to the corresponding author.

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