It has been shown that approximately 30% of patients undergoing cataract surgery have corneal astigmatism of more than 0.75 diopters (D). Postoperative residual astigmatism decreases unaided visual acuity and quality of vision. A better understanding of the effect of posterior corneal astigmatism and the availability of more accurate toric intraocular lens (IOL) predictions have improved the ability to correct astigmatism with toric IOLs during cataract surgery, even in patients with low preexisting cylinder.

Toric IOLs need to be positioned accurately on the intended meridian to have their desired effect. Each degree of rotational misalignment of the IOL results in a loss of approximately 3% of cylinder power correction. Thus, a deviation of 10° from the intended meridian results in a loss of approximately one-third of the astigmatism-reducing effect of the toric IOL.

There are different sources of errors that can lead to a rotational misalignment of a toric IOL. First, there are diagnostic challenges such as measurement inaccuracies or inconsistencies of the anterior corneal curvature, irregularity in astigmatism, or inaccurate prediction of the posterior corneal astigmatism. Second, inaccurate reference and target marking of the eye (eg, due to cyclotorsion) can lead to misalignment. Third, there are procedural sources of error such as surgically induced astigmatism and inaccurate positioning of the lens at the time of surgery. Finally, the lens can potentially rotate later even after proper positioning during surgery. Although the latter was a significant issue with the early toric IOLs, this problem is now less frequently encountered with modern toric IOL designs.

ABSTRACT

PURPOSE: To compare the accuracy of two common reference marking methods for toric intraocular lens alignment before and after using the novel toriCAM application.

METHODS: In this prospective, randomized study, 22 participants were randomly allocated to two groups, either freehand or slit-lamp–assisted marking. Corneal markings at 0° and 180° were made using either method. The toriCAM application on a smartphone was then used to assess the rotational alignment of these markings and compared to the actual alignment as measured by the Zaldivar calipers on the iTrace Topographer (Tracey Technologies, Houston, TX) as a reference. The errors in marking with and without using the application were analyzed for all patients in each cohort and determined for each marking method.

RESULTS: Twenty eyes of 11 patients were marked using the freehand method and 20 eyes of the other 11 patients were marked using the slit-lamp method. The mean absolute error of all markings before toriCAM adjustment was 3.18° ± 2.22°. This was significantly reduced to 1.28° ± 1.34° after using the application (P < .001). This improvement was also noted separately in the freehand and slit-lamp groups. Comparison of the freehand and slit-lamp methods did not show any statistically significant difference in accuracy at both time points.

CONCLUSIONS: The novel toriCAM application is able to significantly improve the accuracy of reference marking for both freehand and slit-lamp methods.

Reference marking of an eye to establish the appropriate meridian prior to toric IOL implantation is a challenging process. Inaccurate preoperative marking of the eye can, as mentioned, contribute to postoperative misalignment of the toric IOL and subsequently to residual postoperative astigmatism.\(^8\)

Many different methods for reference marking are currently available, but no gold standard has yet been defined for the preoperative marking of eyes and all methods have inherent inaccuracies. Some of the most prevalently used marking methods are the freehand and slit-lamp methods. Despite reports that other methods might be more accurate,\(^13\) both methods have a low learning curve and are efficient and independent of further equipment. Recently, a smartphone application called toriCAM has been developed by Professor Graham Barrett. This software is able to assess the rotational misalignment of any preset reference marks and therefore should help increase the accuracy of any manual reference marking method.\(^14\)

The primary objective of this study was to determine whether the toriCAM application increases the accuracy of preoperative reference markings (with either the freehand or slit-lamp method) prior to toric IOL implantation. The secondary objective was to assess and compare the accuracy of freehand and slit-lamp marking.

**PATIENTS AND METHODS**

This prospective, comparative study was approved by the ethics committee of Sir Charles Gairdner Hospital, Perth, Australia, and was performed in accordance with the tenets of the Declaration of Helsinki and Good Clinical Practices.

Twenty-two patients and staff volunteers were assessed and informed consent was obtained. All patients and staff volunteers were from the outpatient ophthalmology clinic at Sir Charles Gairdner Hospital, Perth, Australia.

The exclusion criteria were: age younger than 18 years, conjunctival or corneal pathology, and preexisting allergies to eye drops or topical anesthetic agents. Participants were randomized using a standard random number generator from our independent hospital statistical team into two groups with 20 eyes for each of the marking methods.

All reference markings were performed by the same experienced cataract surgeon (AP), who is accustomed to both the slit-lamp and freehand marking methods. After setting the marks, the surgeon then used the toriCAM application and recorded the given correction in degrees for each eye. Subsequently, the iTrace Topographer (Tracey Technologies, Houston, TX) was used to capture an image of the eye as the measurement method of reference.

The patients and participants did not undergo cataract surgery after the marking process.

**SLIT-LAMP MARKING METHOD**

Each eye of the patient was anesthetized by a drop of preservative-free oxybuprocaine eye drops (Minims; Bausch & Lomb, Rochester, NY). The head of the patient was then positioned at the slit lamp (Haag-Streit AG, Koeniz, Switzerland) with the chin and forehead fixed if need be with the help of another staff member. The limbus was dried with an absorbent cellulose spear (Merocel; Beaver-Visitec International, Waltham, MA) at 0° and 180°. The slit beam then was turned in the horizontal position and the participant was asked to fixate on a distant target at head height with the contralateral eye. Next, the slit beam was focused on the center of the cornea. Then two limbal marks were placed sequentially nasally and temporally at the horizontal meridian with a surgical marking pen (purple surgical, CE0120 Ref: PS3150). If the slit beam was not long enough to cover the white-to-white distance of the eye, the nasal and temporal sides were marked sequentially based on the outer margin of the beam light focused on the center of the cornea.

**FREEHAND MARKING METHOD**

Each eye of the patient was anesthetized by a drop of preservative-free oxybuprocaine eye drops (Minims). The head of the patient then was positioned if need be with the help of another staff member. The limbus was dried with an absorbent cellulose spear (Merocel; Beaver-Visitec International) and the participant was asked to fixate on a distant target at head height with the contralateral eye. The surgeon always stood obliquely to the right side of the participant irrespective of the eye that was being marked, using his right hand for the marking. A surgical marking pen (purple surgical CE0120 Ref: PS3150) was used to mark the limbus nasally and temporally at presumed 0° and 180°.

**TORICAM APPLICATION**

The toriCAM is a newly developed smartphone application. Its main aim is to improve the accuracy of preoperative reference markings prior to toric IOL implantation. The software is based on the accelerometer and gyroscope built into modern smartphones, which can provide a precise level indicator. It further provides a photographic analysis to identify the rotational deviation of the marks from the real horizontal meridian. The toriCAM software can be downloaded from the App Store (Apple Inc., Cupertino, CA) for free. In this study, the toriCAM application was used in every eye immediately after using either of the two marking methods as described above.
Specifically, the head of the participant was aligned again if need be with the help of an assistant. All eyes were approached with an iPhone 5 (Apple, Inc.) from the right hand side of the participant. The application uses the built-in fixation light in close proximity to the camera lens and the participant was asked to fixate on this light while the contralateral eye was occluded. The iPhone was then rotated until the horizontal red line on the screen was aligned with both blue marks on the patient’s eye. A series of photographs was taken with the software and the surgeon then chose the image with the best overall alignment and quality. The virtual, presumed true reference axis is provided by the application and was recorded for each examination as seen in Figure 1.

**Measurement of Reference**

The iTrace Topographer was used for analysis of the eye markings and as the measurement reference. Specifically, the participant was placed in front of the iTrace Topographer and his or her head was carefully aligned with the chin and forehead fixed with the help of an assistant. A corneal topography was recorded and the image was later analyzed with the toric planning software provided by the iTrace device. The Zaldivar calipers were aligned to the center of each of the marking dots and the rotational misalignment was noted as demonstrated in Figure 2.

In the case of vertical misalignment where the degree could not directly be read on the Zaldivar calipers, the following formula was used as demonstrated by Woo et al.\(^\text{13}\): \(X = A / 2 + B / 2\), where \(X\) is the total rotational deviation in degrees, \(A\) is the angle between the horizontal reference meridian and the line connecting the corneal center and the marking point on the right limbus, and \(B\) the angle between the horizontal reference meridian and the line connecting the corneal center and the marking point on the left limbus of the cornea; both \(A\) and \(B\) are given by the Zaldivar calipers on the toric planning software as seen in Figure 2.

**Statistical Analysis**

All data were analyzed using the R environment for statistical computing software.\(^\text{15}\)

All patients’ eyes were treated as independent observations. Means and standard deviations are presented for each variable. Marking errors were calculated for each eye as the absolute difference between the freehand or slit-lamp markings and 180°, both before and after toriCAM adjustment. The marking errors before and after toriCAM adjustment were compared using a paired \(t\) test for the entire cohort, as well as separately for the freehand and slit-lamp cohorts.

Wilcoxon–Mann–Whitney tests were used to compare the freehand and slit-lamp marking errors before and after toriCAM adjustment. Significance was set at the 5% level.

**RESULTS**

The study enrolled 22 participants and 40 eyes of patients or staff volunteers. Four participants participated with only one of their eyes; all other participants had both eyes tested. All patients were randomized into either the slit-lamp marking group or the freehand marking group, with 11 participants in each group. No participant had to be excluded from the study.

A clockwise misalignment was defined as numeric negative and a counterclockwise misalignment as positive. The mean rotational misalignment compared to the measurement of reference was -1.875° in all eyes. The mean error was -1.8° for the slit-lamp marking group and -1.95° for the freehand marking group. In both marking groups, 13 of 20 measurements were misaligned in a clockwise fashion. The mean rotational error after using the toriCAM application was -0.325° in all eyes (-0.1° in the slit-lamp marking group and -0.55° in the freehand marking group).

The mean absolute error compared to the measurement of reference was 3.18° ± 2.22° for the entire cohort. This was significantly reduced to 1.28° ± 1.34° after additionally using the toriCAM application (\(P < .0001\)). This translated to an average reduction in marking error of 59.8% for the entire cohort.

Table 1 and Figure 3 illustrate the absolute mean marking errors with standard deviation bars, both before and after toriCAM adjustment in the slit-lamp and freehand marking groups.
and after toriCAM adjustment, for the entire cohort and broken down into the freehand and slit-lamp groups.

Adjusting the estimated reference axis using the toriCAM application provided a more accurate reference mark in 60% of the cases, made no difference in 32.5%, and reduced the accuracy in 7.5% of cases.

There were no statistically significant differences in the absolute marking error between the slit-lamp and freehand methods either before or after toriCAM adjustment.

**DISCUSSION**

Determining an accurate preoperative reference prior to marking of the toric IOL axis is essential for optimal postoperative refractive outcomes using conventional marking methods. Our study assessed and compared slit-lamp and freehand marking method with and without the toriCAM application. The iTrace Topographer with its built-in scale and photographic method using the Zaldivar calipers was used as an objective measure of the actual marked reference axis as published previously by Woo et al.\(^\text{13}\)

This study assessed and compared the accuracy of the freehand and slit-lamp marking methods. Both the
In our study, the mean absolute error of combined freehand and slit-lamp marking was significantly reduced after adjustment with the toriCAM application. Looking at the slit-lamp and freehand marking groups individually, the mean absolute error decreased from 2.8° to 1.4° and from 3.55° to 1.15°, respectively. These findings indicate that the toriCAM application potentially is able to significantly reduce reference marking errors, thus potentially improving the accuracy of both marking methods. The use of the toriCAM application appears to be of greater benefit to the freehand than the slit-lamp method of marking. Furthermore, the mean absolute error dropped to a similarly low level regardless of whether the slit-lamp or freehand marking method had been used. This result suggests that the use of the application could also potentially improve other preoperative marking methods.

While performing this study, we learned that inadvertent head tilt of the patient during the marking process is a significant source of marking error. This is particularly relevant when the marking is being performed with a device visible to the patient. We believe that one of the reasons why a smartphone application like the toriCAM is effective is that the head alignment of the patient is easier to control when using a “non-touch” measurement. However, the reference marks given by the toriCAM are virtual, which poses a challenge when calculating the desired toric target axis intraoperatively. A specifically designed toriCAM dual-axis marker that allows the reference axis to be set independently from the target axis can avoid this potential source of error.

Recently, image-guided systems such as the Callisto (Carl Zeiss Meditec, Jena, Germany) or the Verion (Alcon Laboratories, Inc., Fort Worth, TX) have been introduced that determine the reference axis from photographs using limbal blood vessels and iris features. Both systems show the target axis directly when viewing through the surgical microscope. Marking the reference axis is potentially no longer necessary when using these devices, but in some cases registration may not be reliable or feasible and therefore some surgeons still mark the limbus manually even when using an image-guided system.

In a study by Montes de Oca et al., a threedimensional computer-guided system and manual marking were found to be similar in accuracy for toric alignment. In another study comparing the image-guided systems to traditional reference and target marking, Elhofi and Healy showed less postoperative misalignment with the Verion system compared to a pendulum marking method. This methodology is promising, but the technology is relatively expensive and it is yet to be determined whether it is more accurate than traditional marking methods in conjunction with applications similar to the toriCAM.
One of the limitations of our study is that only rotational misalignment was assessed. Theoretically, a vertical misalignment is not as relevant because it can be intra-operatively transposed at the time of the target marking. However, a large vertical misalignment could be another source of error. Vertical misalignment has been assessed in other marking studies before and no statistically significant difference in vertical misalignment between the different marking methods could be found.\textsuperscript{13,17}

In addition, the recruitment of young and cooperative volunteers could have led to an overestimation of the clinical improvement through the toriCAM application because the head alignment was easier than it usually is with patients in the operating room.

Finally, the study is limited to a comparison of different clinical methodologies in toric reference marking rather than clinical outcomes. Therefore, further studies including refractive outcomes with different marking methods are desirable to determine the clinical application of this method.

Despite the relatively small number of patients, this study demonstrated that the novel toriCAM application was, in our hands, able to significantly improve the accuracy of two commonly used marking methods.

**AUTHOR CONTRIBUTIONS**

Study concept and design (AP, TKY, MT, GB); data collection (AP, TKY); analysis and interpretation of data (AP, TKY, MT, GB); writing the manuscript (AP, GB); critical revision of the manuscript (TKY, MT, GB); statistical expertise (AP, MT); supervision (GB)

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