Extended Dehydration of Corneal Allogenic Intrastromal Ring Segments to Facilitate Insertion: The Corneal Jerky Technique

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Purpose: The aim of this study was to describe a new technique to facilitate the insertion of corneal allogenic intrastromal ring segments.

Methods: A single-segment corneal allogenic intrastromal ring segment (CAIRS) was trephined from donor corneas and allowed to markedly dehydrate for 75 minutes before the start of the procedure with a room humidity of 35% to 45%. The duration of the insertion step and the intrastromal segment size at 1 week as measured by optical coherence tomography were compared with previously performed single-segment CAIRS procedures using the conventional technique.

Results: A total of 41 eyes of 36 patients underwent 1-segment CAIRS insertion of the same trephination size (750 μm). Fifteen eyes underwent the conventional insertion procedure, and 26 eyes had a dehydrated segment inserted. The time taken to insert the CAIRS analyzed by surgical video recording starting after the femtosecond tunnel creation and initiation of the insertion to the segment ironing step was 282 ± 103 and 97 ± 23 seconds for the conventional and the dehydrated segment technique, respectively ($P < 0.001$). Anterior segment optical coherence tomography performed 1 week postoperatively revealed similar segment thickness and width of 471.3 ± 54.1 μm and 1285.1 ± 191.0 μm for the conventional allogenic segments and 483.4 ± 58.3 μm and 1227.2 ± 165.2 μm for the dehydrated segments ($P = 0.515$ and 0.314, respectively).

Conclusions: Markedly dehydrated corneal allogenic segments are easier and faster to insert than the nondehydrated ones while maintaining similar sizes intrastromally. This dehydration technique makes the procedure similar to the one with synthetic segments and hence reduces the learning curve.

Key Words: recurrent erosions, customized, phototherapeutic keratectomy, cornea

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Corneal allogenic intrastromal ring segments (CAIRSs) have been recently described by Jacob et al[1] for the treatment of keratoconus (KC). These lamellar tissues are trephined from a human donor cornea and subsequently cut into segments that are inserted into intrastromal tunnels fashioned in the host cornea at a given optical zone to achieve a flattening effect. The latter depends on the thickness of the segment inserted, similar to polymethyl methacrylate (PMMA) intrastromal corneal ring segments. CAIRSs offer the possibility of a wide range of insertion depths with comparable results and less risk of complications.[1,2] Unlike their synthetic counterparts, CAIRSs are nonrigid, pliable, and soft; therefore, thicker segments often represent a challenge to surgeons, particularly beginners, when inserting them in. Parker et al[3] described dehydrating large allogenic segments enough to shrink in size so they would be easily introduced in the tunnels. The segments, however, as described in the published report and accompanying video, remained soft, nonrigid, and easily pliable, which might still pose some technical difficulties during intrastromal insertion especially for the novice surgeon, with prolonged surgical time, compared with synthetic segments. We describe a new technique of significantly dehydrating the allogenic segments after trephination, which renders them rigid enough to be held with a pair of forceps without losing shape, to facilitate their insertion into the intrastromal tunnel, in a very similar manner to synthetic intrastromal corneal ring segments. These markedly dehydrated segments behave like biopolymers: they are rigid, yet pliable enough to follow through in the tunnel without the need to push them in with an instrument. We dub this technique the "corneal jerky," in reference to the dried meat tissue.

METHODS

CAIRS insertion procedure was first performed at the American University of Beirut Medical Center in August 2019, and the corneal jerky extended dehydration technique was first applied in May 2020. A retrospective chart review of patients with KC who underwent CAIRS insertion at the American University of Beirut Medical Center was performed between November 2019 and April 2020 for eyes with the conventional technique and then from July 2020 through January 2021 for eyes with the extended dehydration technique. All cases were performed by the same surgeon (S.T.A.). First cases of the new technique were not included in the chart review for the sake of fair comparison and to exclude the initial learning curve as a confounding factor. Nine cases were performed before the series between November 2019 and April 2020 because it was the surgeon's first experience with the CAIRS procedure, and 4 cases were performed before the later series between July 2020 and January 2021. For ease of comparison, and to avoid confounding errors, only eyes that underwent 1-segment implantation were selected, and only large segments cut using the 750 μm double-bladed trephines and with arc lengths between 150 and 170 degrees were included. The study was approved by the American University of Beirut Institutional Review Board (Protocol Number BIO-2022-0160).

The sample size formula for 2 groups comparison was determined. This necessitates computing Cohen d which is $= \mu 1 - \mu 2/\sqrt{((\sigma 1^2 + \sigma 2^2)/2)}$, where $\mu 1$ and $\mu 2$ and $\sigma 1$ and $\sigma 2$ are the means and standard deviations of group 1 and group 2, respectively. Those values were derived from the series of eyes evaluated in the Results section, and accordingly, Cohen d = 185/68.02 = 2.72. Using G*Power software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) for a desired statistical power of 0.8 and significance level of 0.05, and with Cohen d = 2.72, the required total sample size was 22, with each group requiring at least 11 eyes. This figure was below the number of eyes evaluated in each group, 15 for the conventional and 26 for the dehydrated segments; hence, no further recruitment was needed.

Surgical Technique

In both techniques, corneas were obtained from the department's eye bank where they were preserved in Optisol-GS solution (Bausch & Lomb, Bridgewater, NJ) at a temperature of 2 to 8°C. All corneas were optically clear, but had poor eligibility criteria for corneal transplantation, consisting mainly of low endothelial counts (below 1500 cells/mm^2) and/or were beyond 10 days from procurement.

Conventional Technique

The conventional surgical technique of CAIRS insertion was performed according to the method previously described by Jacob et al.[1] Basically donor corneoscleral buttons are procured and the epithelium and endothelium are debrided using surgical sponges. The buttons are subsequently trephined using Jacob double-bladed CAIRS trephines (Madhu Instruments, New Delhi, India) into a ring of stromal tissue, which is subsequently bisected using a 15-degree blade into equal semicircular segments. The double-bladed trephine of 6.5 mm inner diameter and 8 mm outer diameter cuts the Bowman layer with a fixed distance of 750 μm, while trephining the stromal side full thickness. Hence, introducing the segment with the Bowman layer facing the corneal apex ensures a uniform segment thickness perpendicular to the corneal surface, independent of the status of the segment hydration.

The segment is placed on a circular polyvinyl alcohol disk that has been trephined to the desired tunnel optical zone using a dermatological punch. The microscope angle graduation embedded in the eyepiece is then used to trim the segments to the desired arc length. The trephined segments were soft and thus straightened with the Bowman layer to the side to facilitate insertion into the tunnel. Horizontal limbal markings are performed on the patient's eye at the slitlamp at 180 and zero degrees. Under the microscope, the corneal vertex is marked with gentian violet ink mark using a Sinskey instrument, and a 3-prong marker with a central crosshair is used, centered on the corneal vertex, to extend the limbal marks into the cornea. This helps in centration of the intrastromal tunnels and in accounting for cyclotorsion after docking.

Intrastromal tunnels are then created in the host cornea using the LDV Z8 femtosecond laser (Ziemer Ophthalmic Systems AG, Port, Switzerland), with an optical zone of 5.0 to 6.0 mm centered on the corneal vertex, and the trephined allogenic segments are pushed into the tunnels using a Y-rod instrument and pulled from the other side through a femtosecond laser–created incision, diametrically opposite to the main incision from which the CAIRS was introduced. The size of the femtosecond tunnel incision was selected to be 900 μm, and the tunnel depth varied from 250 to 300 μm. No sutures were applied at the end of the procedure. A soft bandage contact lens was inserted and removed after 3 days. Moxifloxacin eye drops (Vigamox, Alcon, Novartis Pharma AG, Basel, Switzerland) were prescribed 4 times a day for 1 week, and prednisolone acetate (Pred Forte, Allergan, Irvine, CA) was given 4 times a day for 1 week then tapered over 1 month. Artificial tears in the form of sodium hyaluronate eye drops were given as needed (Artelac Advanced; Bausch Health, Berlin, Germany).

Corneal Jerky Technique

The corneal jerky technique follows the same steps as the conventional technique from donor epithelial and Descemet membrane debridement, trephination of a stromal annulus, and bisection of the latter into equal semicircular segments with subsequent trimming to the desired arc length. Here, the trimmed CAIRSs were shaped in an arc fashion by aligning them around a circular corneal shield that was trephined using a dermatological punch with a size matching the planned optical zone (5.0–6.0 mm), Figure 1A. The segment was left to air-dry and dehydrate in the designated mold in a separate room in the laser suite for 75 minutes with an average room humidity of 35% to 45% and a room temperature of 20 to 22°C. The surgeon would typically perform laser procedures in the meantime, then would proceed with the CAIRS surgery thereafter. The dehydrated CAIRS became rigid, yet slightly pliable, like a biopolymer, which enables the surgeon to hold the segment with a pair of forceps without losing its shape (Fig. 1B). Subsequently, intrastromal tunnels of 900 μm in width at an optical zone of 5.0 to 6.0 mm were created using the femtosecond laser, and the dehydrated segment was grabbed with a pair of forceps and introduced in the tunnel, very similar to the way synthetic segments are implanted because they were rigid enough to allow insertion with a pair of forceps and without an instrument to shove them in. Great care was taken to avoid irrigation or wetting of the eye before insertion of the segment because it could absorb moisture when near the ocular surface, resulting in softening and loss of its composition and shape.

The **Video** (online). depicts the preparation and the insertion of a dehydrated CAIRS arc segment, which is reminiscent of PMMA segments in both shape and ease of insertion. The eye was then irrigated with balanced salt solution, which immediately hydrated the implanted segment, Figure 1C. The latter was then gently "ironed" by sweeping the overlying corneal surface with the side of a Sinskey hook or similar instruments to unwind twists and folds in the allogenic segment.

Groups Comparison

Recorded videos of the surgical procedures were reviewed, and the time between the start of the segment insertion to the start of the segment ironing step was measured for both groups. This included segment insertion and repositioning within the intrastromal tunnel. The mean and standard deviations were computed. In addition, the anteroposterior segment size (perpendicular to the surface of the segment) and transverse size were measured in both groups using optical coherence tomography (OCT, MS-39; CSO, Florence, Italy) at 1 week postoperatively.

RESULTS

Preoperative Data

Patients from the conventional segment group had a mean age of 29.1 ± 11.2 years, whereas those with dehydrated segments had a mean age of 31.2 ± 14.4 years (P = 0.630). The planned mean femtosecond laser–created tunnel depth was 266.3 ± 15.3 and 273.4 ± 14.1 μm for the conventional and dehydrated allogenic segments, respectively (P = 0.140). All eyes included in the study were planned for 1 allogenic segment to be trephined with a 750-μm double-bladed trephine.

Surgery Time and Course

The time taken to insert the CAIRS, analyzed by video recording, starting after the femtosecond tunnel creation and first attempt to insert the segment until the start of the segment ironing step was 282 ±103 and 97 ± 23 seconds for the conventional and the dehydrated segment technique, respectively (P <0.001). No complications were encountered with both techniques in this small case series.

Intrastromal Size as Measured by OCT

The in vivo intrastromal thickness of the allogenic segments, normal and horizontal to the surface, as measured by OCT at 1 week, was 471.3 ± 54.1 and 1285.1 ± 191.0 μm for the nondehydrated segments and 483.4 ± 58.3 and 1227.2 ± 165.2 μm for the dehydrated segments (P = 0.515 and 0.314, respectively). Figure 1D displays the OCT section of a dehydrated segment 1 week postoperatively while the topographic change compared with preoperative can be seen in Figures 1E, F.

DISCUSSION

Corneal allogenic intrastromal ring segments have recently emerged as a new modality in KC and corneal

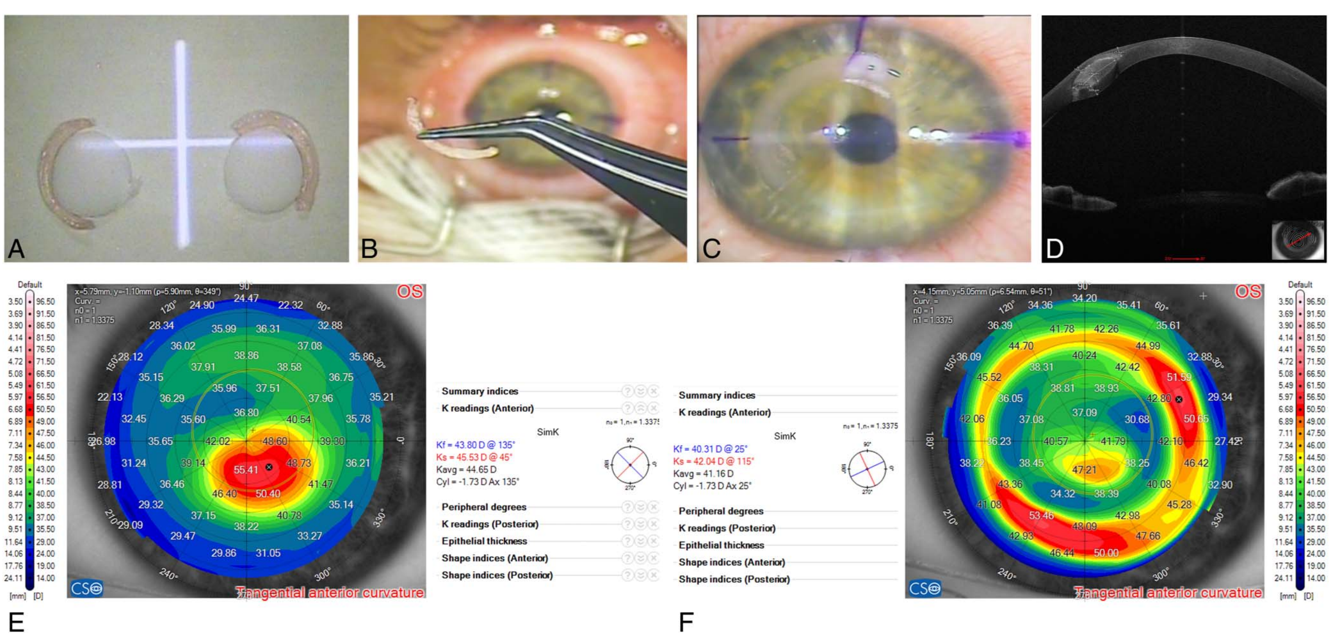

FIGURE 1. A, CAIRSs aligned against a circular mold, in this case, a polyvinyl alcohol corneal shield trephined by a 6-mm dermatological punch. B, Resultant dehydrated segment has an arc shape and is rigid, so it does not lose shape when held with a pair of forceps. C, Segment after insertion into the stromal tunnel and after hydration by irrigating the eye with balanced salt solution. D, Preoperative tangential curvature topography of a KC eye before CAIRS implantation. E, Topography 1 week after implantation of a dehydrated CAIRS in the same eye showing marked improvement in the anterior tangential curvature map. F, Corneal optical coherence tomography scan showing the previously dehydrated intrastromal allogenic segment 1 week after implantation.

ectasia treatment,[1,2] and as an alternative to PMMA segments.[4] Given the same implantation depth as synthetic segments at 400 μm, thicker allogenic segments might be needed to lead to the same clinical effect as thinner PMMA segments because CAIRSs undergo compression once implanted intrastromally, as have been noted in this study. However, because of their allogenic nature, CAIRSs can be implanted at a much shallower level in the stroma without the risk of stromal melting associated with their PMMA counterparts. This would enhance their flattening and regularization effects on the corneal surface. Thicker corneal ring segments have a greater clinical effect and hence are needed in more advanced forms of KC.[4,5] Although this is not often a problem with PMMA segments, for allogenic tissue which is soft, inserting large segments into a tight stromal tunnel might pose a challenge to the surgeon, especially the uninitiated ones. In addition, it prolongs the time of a procedure that is notoriously fast when synthetic segments are used. Parker et al[3] suggested partial dehydration of large segments to reduce their thickness and facilitate their introduction into the stromal tunnel. Although this technique is quite helpful in facilitating CAIRS insertion, it is different than ours because the segments were still described to be soft and nonrigid, and the surgical video accompanying the published technique shows that the allogenic segment is still flaccid and had to be shoved into the tunnels using a Y-rod instrument.

Our described technique dehydrates the trephined corneal segment to a state where it becomes rigid, yet pliable, hence the name "corneal jerky." The rigid segment can be held with a pair of forceps and inserted into the tunnel in the same way as a synthetic segment. Shaping the segment in the form of an arc before marked dehydration, by aligning it along a trephined polyvinyl alcohol disk, makes it even easier to insert. This is because the segment shape matches that of the created tunnel. Newly available devices such as the Awwad CAIRS dehydration mold (Epsilon USA, Chino, CA) simplify this step further by providing a ready-made mold for the trephined segment to sit in and dehydrate while taking the shape of an arc segment at a given optical zone (Fig. 2).

FIGURE 2. Circular mold for aligning the CAIRS and allowing for extended dehydration (Awwad CAIRS dehydration mold, Epsilon USA). The white arrows point to the circular groove where the trephined allogenic segments can be placed while dehydrating and hardening, so they would take an arc shape. It also has graduated degree marks to assist in inking the segments and cutting them according to a desired arc length.

The implanted corneal allogenic segment rehydrated right after irrigation of the eye with balanced salt solution, as can be evidenced intraoperatively in the video, by Figure 1C, and on the slit lamp, minutes after completion of the surgery. In addition, mean segment sizes were similar when measured on OCT images 1 week after the procedure. Most importantly, the insertion of the fully dehydrated allogenic segment was much faster than the nondehydrated segments, and this difference in time of insertion is expected to be even higher for beginner CAIRS surgeons, especially with larger segments.

One limitation of the study is that eyes with the corneal jerky technique were sequentially performed after the ones with the conventional technique, and hence, we cannot exclude improvement in the surgical learning curve over time as a confounding factor, favoring the dehydration technique. However, the difference in surgical time between the 2 techniques is so large that it would be very unlikely that the learning curve was solely responsible for the drastic and sharp decrease in surgical time during segment insertion. Another potential limitation would be the variability in corneal preservation techniques and operating room conditions across centers, which may affect the findings.

In summary, markedly dehydrating trephined allogenic segments result in much faster and easier CAIRS surgery, for beginner and seasoned surgeons alike, especially for larger segments. This is achieved while retaining the same intrastromal size 1 week after implantation as the nondehydrated allogenic segments, as displayed by AS-OCT. In addition, precut, irradiated, and dehydrated forms in the shape of an arc segment, distributed by eye banks, might represent a fast and practical solution for surgeons.

REFERENCES

1. Jacob S, Patel SR, Agarwal A, et al. Corneal allogenic intrastromal ring segments (CAIRS) combined with corneal cross- linking for keratoconus. *J Refract Surg*. 2018;34:296–303.
2. Haciagaoglu S, Tanriverdi C, Keskin FFN, et al. Allograft corneal ring segment for keratoconus management: Istanbul nomogram clinical results. *Eur J Ophthalmol*. 2022;33:689–696.
3. Parker JS, Dockery PW, Jacob S, et al. Preimplantation dehydration for corneal allogenic intrastromal ring segment implantation. *J Cataract Refract Surg*. 2021;47:e37–e39.
4. Kozhaya K, Mehanna CJ, Jacob S, et al. Management of anterior stromal necrosis after polymethylmethacrylate ICRS: explantation versus exchange with corneal allogenic intrastromal ring segments. *J Refract Surg*. 2022;38:256–263.
5. Burris TE, Ayer CT, Evensen DA, et al. Effects of intrastromal corneal ring size and thickness on corneal flattening in human eyes. *J Refractive Surg*. 1991;7:46–50.