REVIEW/UPDATE

Phacoemulsification of the rock-hard dense nuclear cataract: Options and recommendations

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We describe the essential steps in the successful phacoemulsification of the rock-hard, dense cataract. Appropriate and directed preoperative history, physical examination, and diagnostics allow the surgeon to select the best incision, anesthesia, and intended surgical technique for a given dense nuclear challenge. Hard nucleus-specific approaches for hydrodissection, pupil management, and zonular protection then allow the surgeon to approach the rock-hard nucleus with maximum safety. Dense nuclear dismantling options are then discussed in detail along with fluidic and power modulation considerations. Various specific phacoemusification machine settings for rock-hard cataracts from the authors representing several different phaco systems are then presented. The combination of these steps and considerations allow a more successful dense cataract removal and potential restoration of vision for patients. This paper represents the collective experience and advice of the Challenging and Complex Cataract Surgery Subcommittee.

J Cataract Refract Surg 2018; 44:905–916 © 2018 ASCRS and ESCRS

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The rock-hard cataract represents the furthest extremes of cataract formation. At this advanced stage, the nuclei achieve maximum density, the anatomic support structures including the capsule and zonular fibers are often friable or scarred, and the surrounding ocular structures are often less able to recover from the effects of surgery. Although these cataracts represent above average challenges for the phacoemulsification surgeon, they also offer the potential for a greater restoration of vision for the patient and of the quality of life for both the patient and the surgeon when successfully performed.

Pathophysiology of Dense Cataracts

Rock-hard cataracts (dense cataracts) form a broad category of physically hard cataracts that span several types of lens opacities. Specifically, brunescent nuclear sclerotic cataracts appear yellow or brown on examination because of the accumulation of the photooxidation pigment urochrome. Much rarer are black cataracts or cataracta nigra. Histopathology shows increased eosinophilia and homogeneity of the lens fibers in dense cataracts.

Successful removal of dense cataracts is facilitated by careful attention to the history, physical examination, surgical approach selected, anesthesia, incision creation/protection, capsulorhexis, hydrodissection, pupil management, zonular management, nuclear dismantling, fluidics, and power modulation.

History

A thorough history allows for improved surgical planning. Important history details include timing of symptoms, degree of vision loss, comorbidities such as trauma or ocular pathology, visual potential (amblyopia, macular degeneration, glaucoma, etc.), and the patient's age (density escalates with increasing age). Other causes of dense lenses include genetics, smoking, previous trauma, and previous ocular surgery such as a pars plana vitrectomy.

Submitted: July 5, 2017 | Final revision submitted: January 19, 2018 | Accepted: March 7, 2018

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Published by Elsevier Inc.

0886-3350/$ - see frontmatter
https://doi.org/10.1016/j.jcrs.2018.03.038

Knowing the status of the other eye can be helpful as a unilateral dense cataract might suggest trauma, previous surgery, inflammation, or neoplasm.

Significant historical comorbidities that could affect the phacoemulsification include pseudoexfoliation, glaucoma, high blood pressure, clotting disorders, genetic anatomic variants, syndromes or diseases, previous inflammation or trauma, and other past ocular surgeries or disorders associated with lens subluxation.

Physical Examination

Attention to detail in the preoperative examination will increase the likelihood of a successful cataract removal. The first task is to determine the visual potential of the eye. If the lens opacity obscures a view of the retina and optic nerve, alternative strategies can be used. Documentation of an afferent pupillary defect is important for preoperative counseling regarding visual outcome. B-Scan ultrasound (US) can be used to determine whether the posterior pole anatomy is grossly normal. One series of 509 eyes presenting for a B-scan before removal of a dense cataract found 1 of the 509 eyes had a melanoma and 4.5% of the eyes had a detached retina.[1]

One time-tested approach to determine the gross visual potential of an eye is to have the patient attempt to determine the direction of incident light from a muscle light (light projection).[2] Another option for patients with some retained visual function is the Parinaud test where reading is assessed at 12.0 cm with a plus 8.0 diopter addition. The Parinaud test has shown a 94.2% sensitivity and 32.4% specificity for predicting macular outcome.[3]

Blue field entoptoscopy has been shown to be accurate in predicting macular function in eyes with at least 20/400 potential, whereas a light-flash visual evoked response is better at predicting macular function than blue-field entoptoscopy in eyes with worse than 20/400 vision.[4]

The preoperative examination involves grading the lens to determine its density. Increasing brown or black pigment has been shown to correlate with maximum lens hardness, although some lenses with only brownish or greyish discoloration have already reached maximum hardness.[5]

A common cataract grading system is based on clinical observation, where one addresses the type of cataract and the cataract grade based on a scale from 1 to 4. In this paper, rock-hard cataracts are defined as either grade 4, brown, or cataracta nigra. Some white cataracts have a nuclear core that has reached the rock-hard stage. A more repeatable and descriptive grading system is available called the Lens Opacities Classification System III (LOCS III),[6] which has been shown to be highly reproducible for describing nuclear sclerotic cataracts.[7,8]

Fifty-six other lens-grading methods exist, including methods such as the Oxford Clinical Cataract Classification and Grading System[9] and the Emery-Little lens opacities classification system.[10] These grading systems allow clinicians to discuss and study these cases with some degree of objectivity. They also allow clinicians to document these cataracts in a way that affords a clear understanding of the surgical challenges they will face when they later review the chart as part of their pre-cataract surgical planning.

Newer technologies such as Scheimpflug imaging can identify the type of cataract and quantify the grade or severity.[11] Anterior segment optical coherence tomography has been shown to correlate with the LOCS III grading.[12]

Careful assessment of the posterior capsule is important, especially in the setting of trauma or previous vitrectomy; however, this is not always possible because of lens opacity. Lens position, phacodonesis, or differences in anterior chamber depth (ACD) between the 2 eyes might alert the surgeon to loose zonular fibers.

A careful examination of the overall eye health for comorbidities and the general health of the patient will allow the surgeon to determine the ideal method of cataract removal and the most prudent form of anesthesia.

Surgical Approaches

Several surgical approaches could be considered for the removal of a dense cataract including intracapsular cataract extraction (ICCE), extracapsular cataract extraction (ECCE), small-incision extracapsular cataract extraction, phacoemulsification, and femtosecond laser–assisted cataract surgery. Each technique offers its own specific advantages and disadvantages and the best technique for a given cataract will depend on surgeon comfort with the potential techniques, the specifics of the cataract to be removed, the overall health of the eye (zonular support, corneal clarity, endothelial cell counts, etc.), the availability of advanced surgical devices for pupil and zonular management, and the potential availability of vitreoretinal specialist support if required. This paper focuses specifically on phacoemulsification of a rock-hard cataract, therefore the other techniques will not be discussed in any detail.

Dense Cataract Anesthesia

Choosing the ideal anesthesia for a more complex cataract can affect the outcome of the case. Although most straightforward rock-hard cataract cases can be done under topical anesthesia, additional or augmented anesthesia might be required for cases that will take a prolonged period or require extensive intraocular manipulation. In general, if extensive iris manipulation, longer surgical time, or scleral wounds will be necessary, peribulbar or retrobulbar anesthesia might increase patient cooperation and comfort. In very long cases, cases combined with retinal surgeons, or cases with a low potential for patient cooperation, general anesthesia might be preferred. In cases where the potential for complications is high, using the level of anesthesia appropriate for the most complex scenario might be prudent.

Incision

In tackling a complex phacoemulsification case, the surgeon must determine the ideal type and size of the primary incision to make. The location and construction of the main wound will impact every subsequent step in the surgery for the good or bad. Clear corneal wounds can be made quickly and work well in most cases where there is a high probability that phacoemulsification will be successful. Some of the authors of this paper advocate making a surgeon's standard incision to avoid adding variables to these complex cases, whereas others advocate making the primary incision a bit larger for rock-hard cataract cases than for a standard case to decrease the chances of oar locking or thermal injury. The surgeon should recognize that a larger wound will alter the behavior of the surgeon's standard fluid parameters and machine settings might need to be altered.

In cases where the surgeon anticipates a possible need to convert to a large incision ECCE or ICCE, there are several basic approaches: (1) Make a standard clear corneal incision (CCI) and then enlarge it to an 8.0 to 10.0 mm size. Such extended CCIs tend to cause more astigmatism, are harder to seal, and heal more slowly than appropriately constructed limbal or scleral incisions. (2) Make a standard CCI and then move to a different site to create a limbal–scleral incision if conversion is warranted. (3) Create a primary limbal or scleral wound that could be extended if necessary. (4) Extend a corneal wound posteriorly from the 2 original corners into a hybrid "frown" corneoscleral wound which diverges from the limbus at its wings (Video 1, available at http://jcrsjournal.org).

Three-plane wounds are often the easiest to close. For example, a guarded diamond blade or crescent blade can be used to make the initial cut down into the sclera and then a crescent to tunnel up into clear cornea. The anterior chamber can be entered with a keratome blade. Before extending the internal wound, the capsulorhexis can be created. This helps maintain the anterior chamber during this critical stage.

In phacoemulsification cases where the potential for the loss of capsular support is high, one option is to create a near clear or a scleral tunnel that could accommodate an anterior chamber intraocular lens (IOL) or sutured posterior chamber IOL of the surgeon's choice. Although the width of the tunnel might be 6.0 to 7.0 mm in some cases, the internal wound should be just large enough for the phaco tip. This will allow for maintenance of the anterior chamber for the case without excessive wound leak and if the incision needs to be enlarged later in the case, it can be easily performed. If extension of the wound is not necessary, sutures are usually not needed for closure. In this approach, one can be prepared for the largest potential incision required for the outer tunnel and hope that only the smallest internal entry wound is required for the case.

Capsulorhexis in a Dense Cataract

It is crucial that the capsulorhexis be continuous, centered, and adequately sized. Often, visibility is compromised because of the lack of a red reflex. In such cases, staining the anterior capsule with a vital dye such as trypan blue improves visualization of the capsular flap and also facilitates visualization of the capsulorhexis edge during the subsequent stages of the lens removal (Figure 1). It should also be remembered that trypan blue dye might alter the dynamics of the capsulorhexis manuever.[13]

Some cases of a white cataract have a high intralenticular pressure from outer liquefied cortex with a rock-hard nuclear core. In these cataracts, avoiding a wrap-around extension in the so-called "Argentinian blue flag syndrome"[A] is crucial. To preempt this untoward phenomenon, after staining of the anterior capsule, the anterior chamber is over-pressurized with an ophthalmic viscosurgical device (OVD) until the anterior capsule convexity is reduced. The surgeon can then pierce the center of the capsule with a needle mounted on a 3.0 cc syringe half filled with a balanced salt solution and immediately aspirate the liquefied lens material to reduce the positive pressure within the capsular bag. Some surgeons advocate posterior pressure on the hard endonucleus with the needle during aspiration to prevent anterior movement of the lens and anterior capsular stress during aspiration.

It is also important that a closed chamber is maintained to decrease the chances of peripheral extension of the capsulorhexis. An OVD is mandatory in maintaining a pressurized chamber. The egress of OVD during the maneuver can compromise the pressurization. Many surgeons further ensure stable pressurization by creating their capsulorhexis through small paracenteses before making the main incision. Microincisional capsulorhexis forceps are advocated by some authors to allow work through smaller incisions to avoid egress of OVD from the eye and consequential shallowing of the chamber (Figure 2). Higher molecular weight cohesive OVDs or viscoadaptive OVDs help to create space as well as flatten the dome of the anterior capsule, facilitating a continuous capsulorhexis.

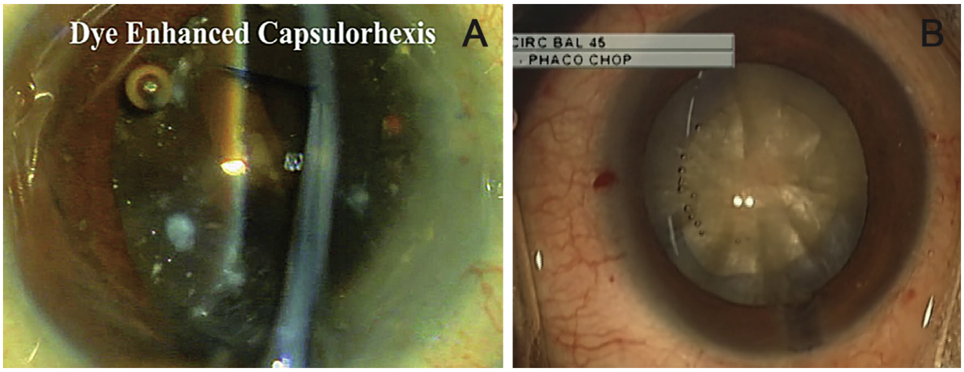

Figure 1. *A* and *B*: Staining of the anterior capsule with trypan blue dye enhances visibility of the anterior capsule in dense cataracts.

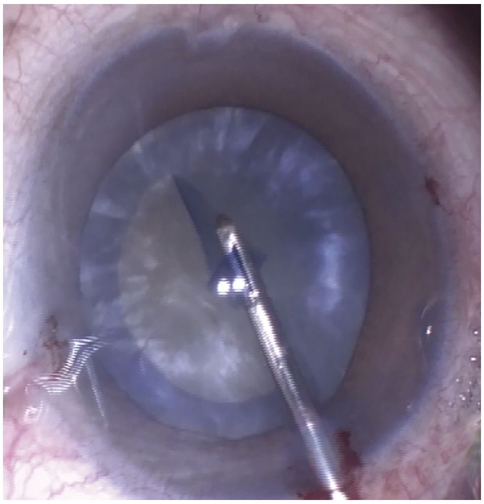

Figure 2. A 1.0 mm corneal paracenteses created to maintain a closed chamber during anterior capsulorhexis.

Some longstanding brunescent cataracts might be associated with anterior capsule fibrosis or plaques. In case of a small central plaque, a capsulorhexis can be made to encompass it or in case of a large plaque, microincisional scissors can be used to create a capsular opening (Figure 3).

The creation of a smaller capsulorhexis confines the mobile hard nuclear fragments within the capsular bag. This facilitates posterior plane emulsification. It also allows the surgeon the option to fixate the IOL with the haptics in the sulcus and the optic captured through the anterior capsule should an alternative fixation strategy be required. However, a capsulorhexis that is too small can endanger anterior capsule split during chopping and makes it harder to elevate quadrants or to convert to an ECCE if required. A larger capsulorhexis makes it easier to mobilize fragments, but might result in fluid current induced propulsion of fragments out of the bag and contact with the endothelium. The state of the zonular fibers and the endothelium might alter the surgeon's choice of capsulorhexis size. Some surgeons purposely start with a small controlled rhexis and then enlarge it later in the case as needed[14] (Figure 4).

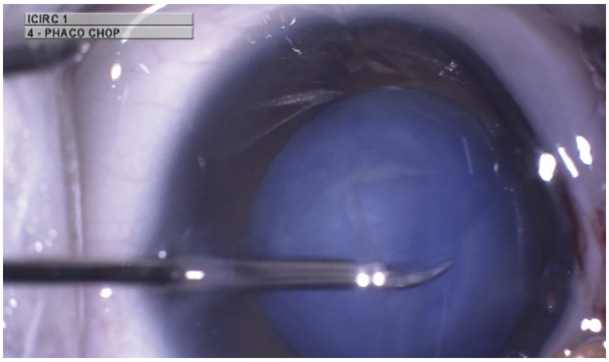

Figure 3. Microincision scissors used to excise anterior capsule plaque.

Cortical Cleaving Hydrodissection

In dense cataracts, there is an increased possibility of a sudden blowout of the posterior capsule during cortical cleaving hydrodissection[15] because of a bulky nucleus preventing egress of the injected fluid. This is especially true in eyes where the capsulorhexis is small and can be recognized by the "pupil snap sign."[16] In these eyes, immediate decompression of the nucleus upon its forward movement can prevent an intraoperative capsular block. Also, careful and gentle cortical-cleaving hydrodissection should be performed in these eyes.

Dense cataracts might resist rotation after single-quadrant cortical cleaving hydrodissection because of corticocapsular adhesions (Figure 5).[17] Multiquadrant hydrodissection (Figure 6) helps to cleave the corticocapsular adhesions making rotation easier.[17] Also, by performing multiple gentle fluid injections, there is less chance for a sudden buildup of intracapsular pressure. In cases of adherent white cortical plaques, viscodissection might permit more facile nuclear manipulations.

Pupil Management

Management of the rock-hard cataract is made even more challenging in the presence of a small pupil or floppy iris. Small pupil size and dense nuclear sclerosis are risk factors associated with an increased incidence of posterior capsule rupture and vitreous loss.[18] Anterior chamber depth might

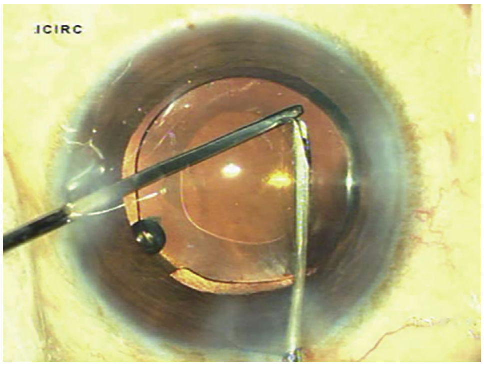

Figure 4. The enlargement can be started with intraocular scissors or a cystotome. A blunt spatula can provide counter-support as a bent cystotome needle creates a nick in the anterior capsulorhexis margin. Capsulorhexis forceps then spiral out the capsulorhexis concentric to the original capsulorhexis to the desired size.

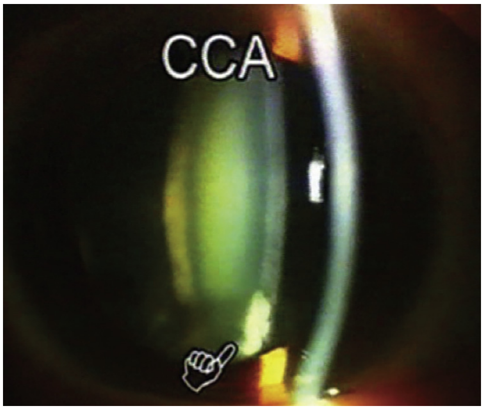

Figure 5. Corticocapsular adhesions (CCA) (*pointing finger*) between the lens capsule and cortex can impede nucleus rotation and increase zonular stress.

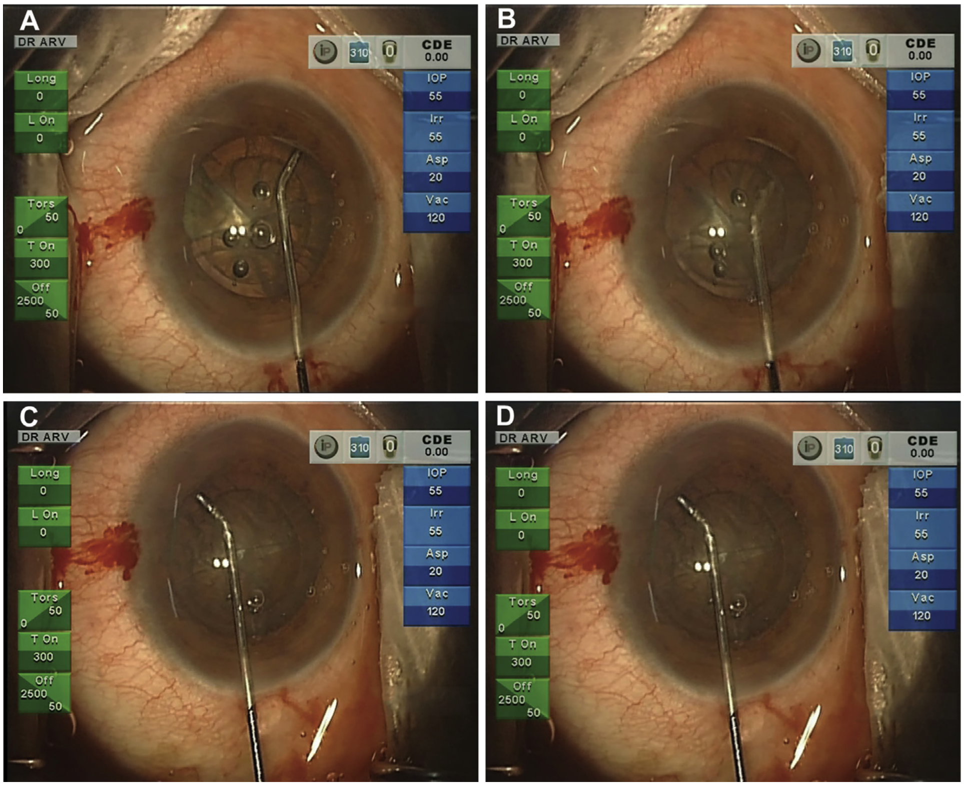

Figure 6. *A* to *D*: Multiquadrant, corticocleaving hydrodissection with bent cannulas will often overcome corticocapsular adhesions and allow a more zonular-friendly rotation.

be decreased in the setting of a brunescent lens, leaving less room for surgical maneuvers.

Increased intraocular manipulations along with decreased anterior chamber size increases the risk for iris trauma in these cases. Therefore, efforts should be made to achieve adequate pupillary dilation. This should begin preoperatively by allowing extra time for topical mydriatic agents to take effect. Pretreatment with a topical nonsteroidal antiinflammatory drug (NSAID) might be helpful in preventing intraocular miosis as well.[19–21] Intraoperative use of intracameral mydriatics and/or analgesics, such as phenylephrine/preservative-free lidocaine or phenylephrine/ketorolac infusion, can help maximize and maintain intraoperative pupil diameter.[22–24]

In the presence of intraoperative floppy iris syndrome (IFIS), cataract surgery with a rock-hard lens becomes extremely challenging and is associated with a higher risk for complications.[25] In addition to the standard pupil management eyedrops, pharmacological adjuncts such as pretreatment with atropine might be considered; intraoperative phenylephrine or epinephrine injected under the iris are advocated by some surgeons.[26] However, pretreatment with atropine has been found to result in smaller intraoperative pupil sizes than a standard preoperative topical dilation regimen.[27]

Use of a femtosecond laser facilitates a consistent preprogrammed capsulotomy size and it might also be helpful in lenses with high intralenticular pressure to reduce the chance for the Argentinian flag sign.[A] However, it has the potential for post-laser pupillary miosis, especially in those with poor preoperative dilation.[28] This might be attributable to prostaglandin release, which has been documented to occur at the time of the femtosecond laser–assisted capsulotomy[29]; however, there is evidence that this can be mitigated with the use of preoperative NSAIDs.[30]

The purposeful instillation of an OVD can be helpful in maintaining or improving pupillary dilation.[31] This is most effective if the OVD is aimed directly at the pupil margin in the direction the surgeon wants the pupil margin to move, thereby pushing it into a more dilated position. Cohesive OVDs are more effective at causing viscomydriasis, but are more easily evacuated with active fluid flow. This would cause a loss of viscomydriatic effect. Dispersive agents are somewhat less effective at causing viscomydriasis, but are better retained. If the aforementioned OVDs are ineffective in achieving sufficient pupillary dilation, a viscoadaptive OVD might be effective.

If pupillary dilation is still insufficient, mechanical pupillary dilation could be considered. Options include mechanical stretching of the pupil with 2 Kuglen hooks or a mechanical pupil dilator (Beehler pupil dilator, Moria, Inc.). Many surgeons prefer options that both dilate and maintain the pupil, such as iris retractors or pupillary ring expansion devices.[32] In IFIS-associated pupillary miosis or instability, a fixed pupillary expansion device is advisable because mechanical stretching is less effective in this setting and can be detrimental.[33] Iris hooks give the surgeon additional options if the zonular fibers are later found to be loose because they can be advanced from the iris margin to the capsular margin to increase bag stability if required.

Zonular Management

Management of a dense cataract in the setting of known preexisting zonular weakness or conditions such as pseudoexfoliation associated with advanced cataract and zonular weakness require careful preoperative planning.[34,35] During surgery, early signs of zonular weakness include difficulty puncturing the anterior capsule and wrinkling of the anterior capsule or movement of the lens–bag complex during capsulorhexis creation. Temporary capsular support hooks, temporary iris hook fixation of capsule segments, permanent capsular tension rings (CTR), sutured fixated capsule segments or rings, or conversion to large incision ECCE or ICCE might be required in cases of extreme zonular weakness.[34,35] We recommend assuming that the zonular fibers are weak in cases of rock-hard cataract removal and using zonular-friendly techniques from the outset of the case such as attentive multiquadrant hydrodissection, 2-handed lens rotation techniques, and tangential stripping of cortical material to add an extra measure of safety. Some advocate torsional US as more zonular friendly than pure longitudinal US.[36]

Early placement of CTRs can be more difficult in these dense nuclear cases because of the larger size of the nuclei and the lack of a cortical cushion. If there is not sufficient space to safely place the CTR early in a loose zonule case, capsular support hooks can be placed until enough room is created through nuclear disassembly to place the CTR. The practice of placing the ring "as late as possible, but as early as necessary" applies in these rock-hard cataract cases.[B]

Nuclear Disassembly

Disassembly of the dense nucleus can be quite challenging for a variety of reasons. First, the lens fibers are very hard and firm and tightly adherent to each other. This can make chopping more difficult because the sections might not separate. Second, there might be very little or no cortical cushion between the lens and the capsule. Some dense lenses are less amenable to vertical chopping because even a sharp-tipped chopper will overstress the zonular fibers if one tries to impale the dense nucleus anteroposteriorly. For the horizontal chopping maneuver, the chopper hook must go peripheral to the dense lens; however, there is little physical space to place a second instrument outside of the nucleus but inside of the capsule. Furthermore, we have seen (more than once) the orthogonal finger on a chopper break off entirely when facing an especially firm lens. In addition, the length of the chopper tip must extend, in depth, at least past the mid depth of the lens.

The physics of a chopping maneuver are maximized when the entry incisions of the chopping instrument and the holding instrument (the phaco tip) are relatively close to each other so that the forces are well apposed. Accordingly, making the paracentesis incision for the chopper side instrument within 1.5 clock hours from the phaco incision will permit more facile splitting of the nuclear core. If the side port is 90 degrees (3 clock hours) away, forces applied to chopping might result in unintended rotation of the nucleus during an attempted chop.

For these dense lenses, standard lens removal techniques often need to be modified. Many surgeons find it helpful to debulk some of the central nuclear core within the confines of the capsulorhexis margin (Figure 7) to create some working space.[37–39] This central space provides room to emulsify the nuclear fragments at a posterior plane, within the capsular bag and away from the corneal endothelium (Figure 8). Also, creating a thin trench facilitates complete division of the nuclear fragments so that they do not remain attached in the center. Debulking the center makes horizontal chopping techniques more viable. However, the grooving of a trench can place additional stress on the zonular fibers, especially if significant longitudinal phaco energy is required. Matching the phaco power to the density of the lens can minimize this.

Chopping techniques in cases of hyperdense lenses allow a surgeon to chop off relatively small more manageable "pieces of pie," whereas each of the quadrants from a 4 quadrant divide-and-conquer technique can still be rather large and unwieldy within the confines of the capsular bag. This allows easier emulsification at a desired posterior plane. As a general rule, the more dense the nucleus, the greater the advantage of creating additional smaller fragments (Figure 9).

For surgeons who prefer to create grooves for a divide-and-conquer approach, making these grooves wider than usual can be very helpful in creating some extra working space. Such grooves should be deep enough to allow the sections to be split off from each other and about twice as large as in an average lens.

As each segment is chopped, there is frequently an incomplete split at the posterior plate of the lens. This can result in the fragments staying adherent to each other. There might be a temptation to bring the phaco probe out of the central safe zone; however, this temptation should be suppressed. If the segments do not mobilize, the chopper tip can be used to pull a piece centripetally, provided that debulking has created adequate space for them to centralize. Once the first few pieces are removed, the subsequent sectors are easier to remove.

When the posterior plate is accessible, additional dispersive OVD placed beneath it will yield a supplemental cushion of protection for the posterior capsule. After enough plate has been removed to access the posterior capsule space, an IOL can be injected underneath the remaining nuclear material to prevent inadvertent posterior capsule damage, which is most likely to occur in the latter stages of emulsification. The plate can then be folded in half and emulsified by approaching an edge (Video 2, available at http://jcrsjournal.org).

There are a number of proposed variations on standard chopping techniques for rock-hard cataracts found in the literature. In this paper, we briefly discuss several of those variations.

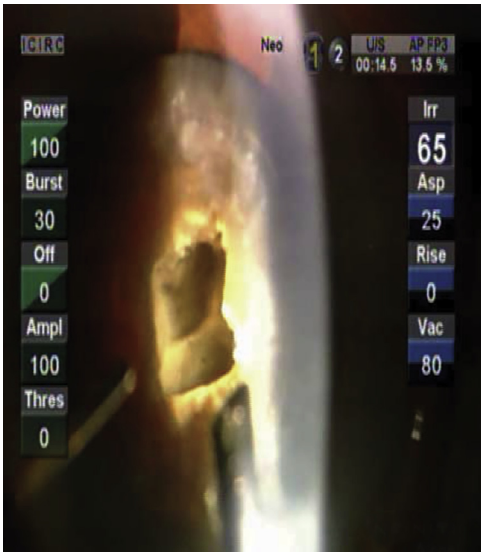

Figure 7. Creation of a deep central trench allows occlusion of the phaco tip at an appropriate depth, more complete division of nuclear fragments, and creates a central space where the first nuclear fragment can be emulsified at a posterior plane.

Multilevel Chop Technique

The multilevel chop technique[40] can be performed with or without the creation of a central groove and can be used for vertical and horizontal chop actions.

Vertical Chop Action After creating a central groove, the phaco tip is introduced into the nucleus (Figure 10, *A*). The vertical element of the chopper is depressed posteriorly within the lens fibers, keeping it adjacent to the tip (Figure 10, *B*). This initiates a partial crack. The phaco tip is then reintroduced at a more posterior plane than the first chop and the chopper is also repositioned at a posterior level within the crack (Figure 10, *C*). A combination of the vertical chop and lateral separation is performed (Figure 10, *D*). This second chop usually separates the posterior lens fibers completely, although an even deeper positioning of the

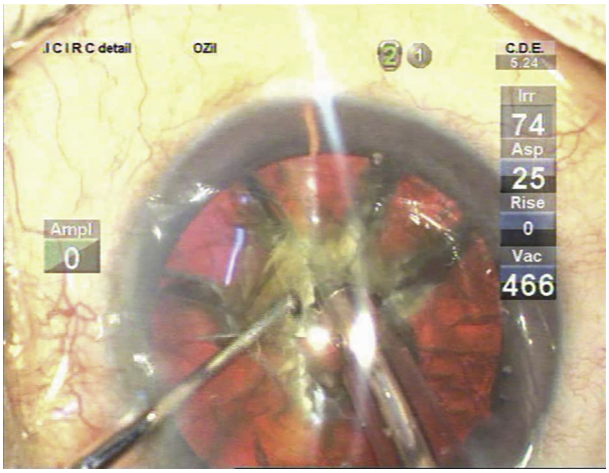

Figure 9. Creation of multiple small nuclear fragments.

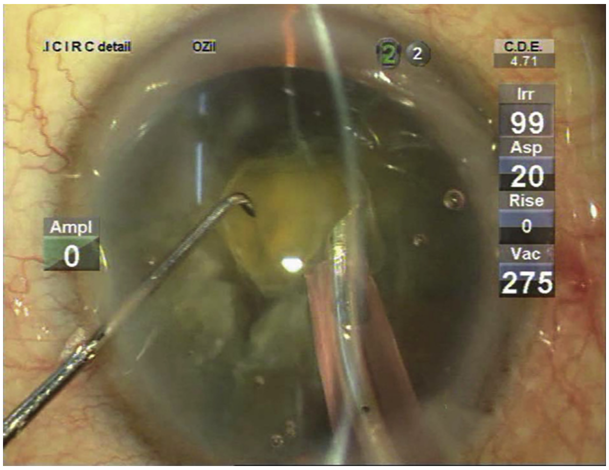

Figure 8. Emulsifying nuclear fragments at a plane away from the corneal endothelium.

phaco probe for a third crack can be carried out if required (Video 3, available at http://jcrsjournal.org).

Horizontal Chop Action The probe is introduced in the lens substance in the distal midperipheral region (Figure 11, *A*). The chopper is placed at the equator and moved toward the occluded phaco tip (Figure 11, *B*). The probe is then repositioned proximal to the first crack attempt while the chopper is positioned inside the crack and moved toward the phaco tip (Figure 11, *C* and *D*). This could be done a third time if necessary by placing the phaco probe proximal to the second attempt. This method often requires higher vacuum than the vertical multilevel chop (up to 600 or 700 mm Hg depending on nuclear density) (Video 4, available at http://jcrsjournal.org).

Tilt-and-Crack Techniques

There are several reported variations on this theme where the lens is impaled with the phaco tip and the distal pole of the lens is tilted up out of the capsular bag.[41–43,C] This gives direct access to the posterior leathery plate so the chopper can be passed behind the plate and more effectively chopped. The concern with this technique is significant stress on the zonular fibers. Later iterations of the tilt-and-crack technique describe using a larger than normal capsulorhexis to decrease zonular stress during the maneuver (6.0 mm),[41] (6.0 to 7.0 mm),[42] or an elliptical capsulorhexis (7.0 mm to 5.5 mm).[43]

Decrease-and-Conquer Technique

In this technique, the superficial epinucleus is cracked and pealed back from the denser endonucleus. The endonucleus is then isolated and phacoemulsified. The remaining epinuclear plates are then emulsified.[44]

Drill-and-Chop Technique

There are several variations on the drill-and-chop technique depending on the type of chopper preferred.[45] These involve impaling the phaco tip straight down into the nuclear material, making as small a bore hole as possible

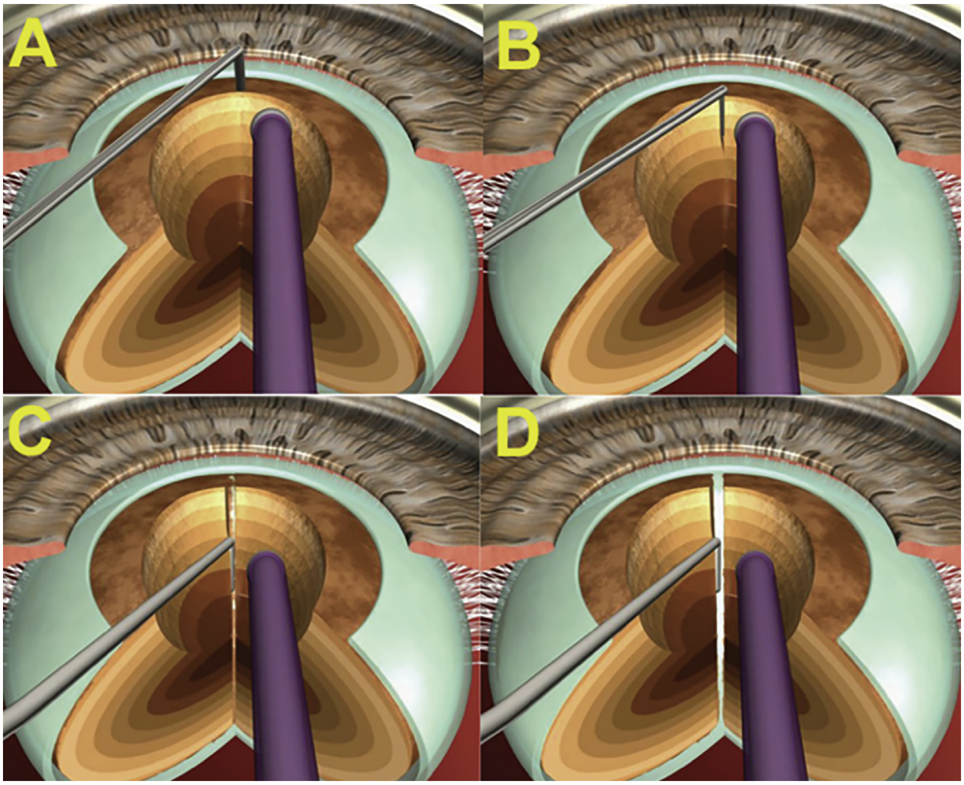

Figure 10. Vertical chop technique. *A*: The phaco tip is introduced into the nucleus. *B*: The vertical element of the chopper is depressed posteriorly in the lens fibers, keeping it adjacent to the tip. This initiates a partial crack. *C*: The phaco tip is reintroduced at a more posterior plane. The chopper is also repositioned at a more posterior level within the crack. *D*: A combination of vertical chop and lateral separation is performed with the chopper while the probe holds the occluded lens material in a stationary position.

into the very deep layers of the nucleus. If the tip is deep enough, 1 chop can often defeat even the most challenging posterior plates. The authors have found these techniques to be very efficient when the correct depth is found; however, it is often difficult to gauge the percent of penetration within the narrow borehole.

Rock-hard cataracts are often thicker than softer lenses, so there is a tendency to not achieve adequate depth. Statistics argue that a surgeon could compensate by moving deeper into such lenses. This would increase efficiency, although statistics would also argue that eventually the surgeon will encounter a thinner than normal nucleus with a

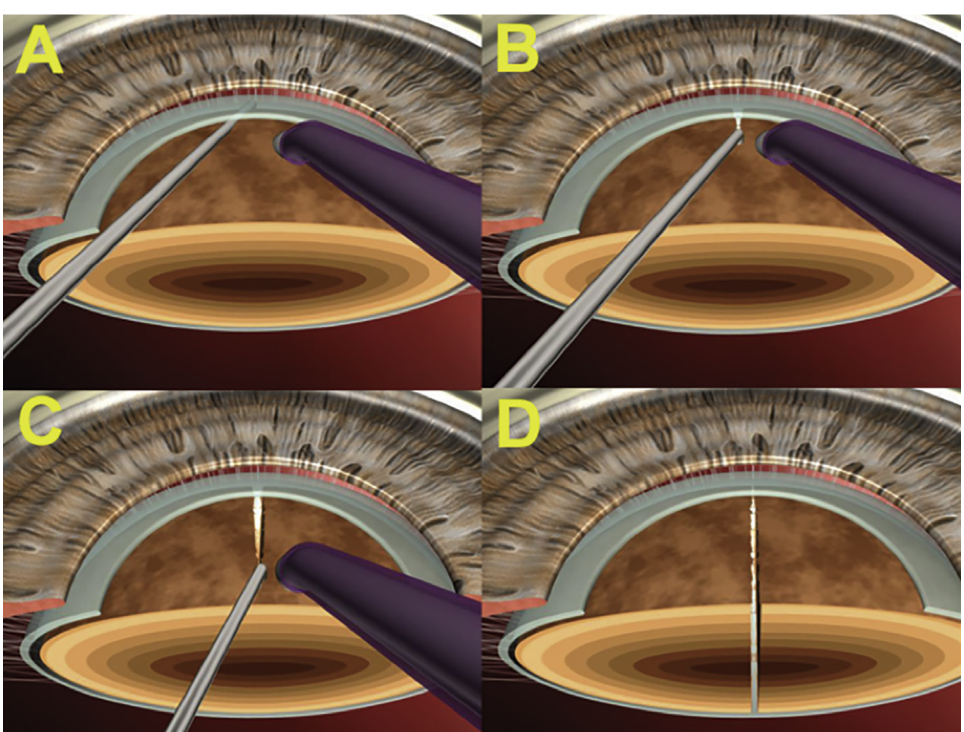

Figure 11. Horizontal chop technique. *A*: The probe is introduced into the midperipheral region of the lens substance. *B*: The chopper is placed at the equator and moved toward the occluded phaco tip. *C* and *D*: Subsequently, the probe is repositioned centrally while the chopper is positioned inside the crack and moved toward the phaco tip.

resulting posterior capsular rupture. Quantifying lens thickness ahead of time would decrease the chances for this complication.

Femtosecond Laser–Assisted Nuclear Disassembly

Femtosecond laser–assisted cataract surgery for the rock-hard cataract is a technique in evolution with a paucity of peer-reviewed claims at time of this publishing. Preplaced chopping planes and nuclear softening provided by the femtosecond laser can be helpful in nuclear disassembly. These laser-assisted techniques have the potential to decrease intraocular manipulations, intraocular phaco energy times, endothelial loss, and zonular stress.[46–48] The benefit of femtosecond nuclear softening is limited by the depth of optical penetration of the laser in optically dense cataracts. Time and further study will better determine the usefulness of femtosecond techniques in these cases.

Manual Micro-Interventional Endocapsular Disassembly

Manual disassembly of the nucleus can be accomplished with a disposable microfilament device (miLOOP; Iantech, Inc.).[49] The device uses a small nickel and titanium (Nitinol) ring that can open to a 10.5 mm radius and then be contracted to a 1.5 mm radius. The ring is opened in the anterior chamber and fed under the anterior capsule (Figure 12). The loop is then rotated around the lens in the space between the nucleus and the posterior capsule (Figure 13, *A* and *B*). At this stage, the loop encircles the nucleus (Figure 14). When the loop is contracted, it cuts the nucleus in half. A second instrument is often required to hold the nucleus in place as the ring is contracted. One study showed that this technique decreased average phaco time in brunescent lenses.[D] In addition, it might prove to be particularly helpful in cases with leathery posterior plates.

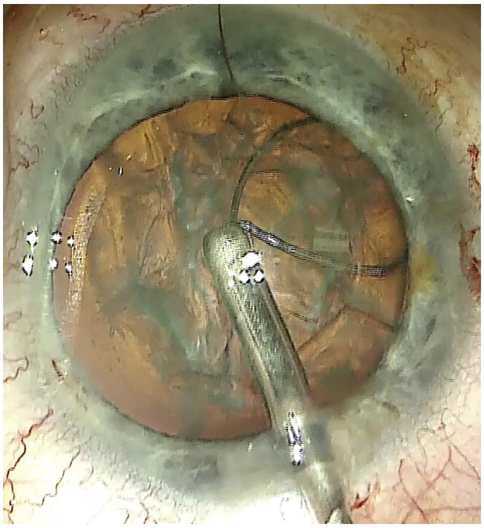

Figure 12. The nickel and titanium ring is placed into the anterior chamber and fed under the anterior capsule.

Fluidics

A proper balance between inflow and outflow will maximize anterior chamber stability and decrease the complexity of a difficult case. As a rule of thumb, the goal is to have the same amount of fluid entering the eye as is leaving the eye.

Some surgeons increase their incision size and even go with a larger sleeve size to decrease the chance for thermal wound injury in dense cataract cases. These maneuvers increase the amount of fluid leaving the eye. A stable chamber could only be maintained with such changes if a surgeon increases the amount of inflow to restore balance.

Many systems achieve increased inflow by raising the bottle height. After raising the bottle height, a surgeon can test the chamber stability with the phaco needle in a safe zone before proceeding with nuclear dismantling. If the chamber is not stable, the bottle height can be further adjusted and tested to ensure a good inflow and outflow balance.

Other systems use nongravity forced inflow. In these systems, a target intraocular pressure (IOP) is set. During phacoemulsification, the IOP is monitored and a mechanical forced compression system is used to force fluid into the eye to maintain the desired IOP. This automates certain parts of the inflow and outflow balance equation.

If a phaco system has a fluidics parameter that accounts for incision size, such as an irrigation factor, changes from a surgeon's customary incision size might require an adjustment in the irrigation factor to maintain a good inflow and outflow balance.

Many surgeons use more aggressive aspiration and vacuum settings for rock-hard cataract cases. These settings help overcome the repulsive longitudinal phacoemulsification strokes, improve the vacuum purchase of the hard nuclei, and decrease phaco tip clogging. Higher flow rates will require greater vigilance on infusion bottle bag volumes to prevent depletion.

Higher aspiration/vacuum settings in the face of longer case times significantly increase the amount of fluid that flows through the eye. This evacuates OVD from the eye and places the endothelium at increased risk. Surgeons can mitigate this risk by frequently replenishing dispersive OVD into the anterior chamber for sustained corneal endothelial protection. Care must be taken to run aspiration without phaco energy after each new instillation of OVD to ensure that the added OVD does not clog the tip and cause a thermal wound burn. The use of very high bottle heights and aspiration flow rates can lead to higher intraoperative IOPs, more corneal edema, and increased anterior segment inflammation in the early postoperative period.[50,51]

Ultrasound Power Modulations: Power and Efficiency

The US and fluidic parameters often need to be customized during each stage of the procedure depending on the density of the nucleus as well as other factors, such as pupil

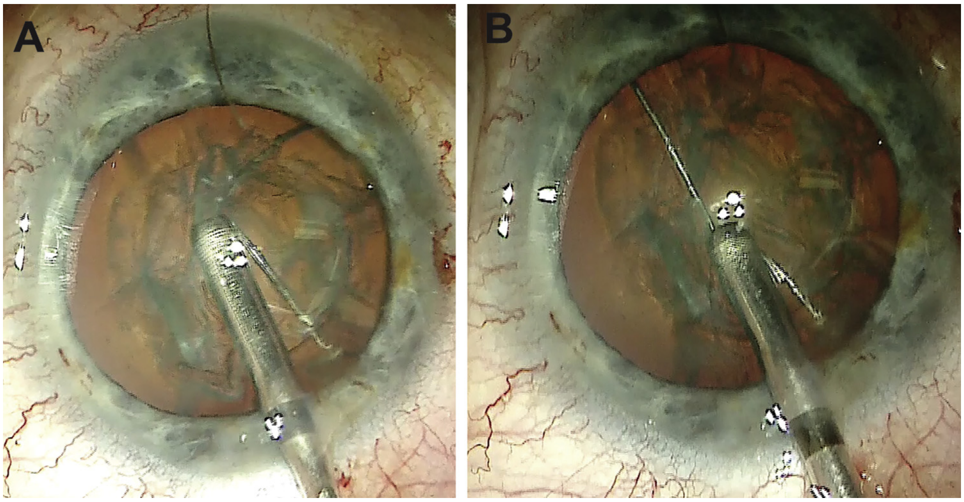

Figure 13. *A* and *B*: The loop is then rotated around the lens in the space between the nucleus and the posterior capsule.

size, ACD, and health of the corneal endothelium. Table 1 shows the changes in the various stages used by one of the authors (A.R.V.).

Power modulation is generally preferable to continuous energy delivery, whether using longitudinal or torsional US, because modulated paradigms reduce total US energy delivered and thus reduce the risk for thermal damage. Unlike continuous energy, intermittent energy delivery allows time for phaco tip cooling between pulses. Also, because longitudinal phacoemulsification causes some repulsion of nuclear material, modulated off time allows the material to be aspirated back to the tip before more phaco power is applied. We prefer phaco systems with options for energy modulations such as pulse mode, burst mode, or micropulse mode to reduce these inefficiencies. The quadrant removal settings for dense, rock-hard cataracts are shown for Drs. Quentin Allen (Figure S1, available at: www/jcrsjournal.org), Michael Snyder (Figure S2, available at: www/jcrsjournal.org), Brandon Ayres (Figure S3, available at: www/jcrsjournal.org), Steve Dewey (Figure S4, available at: www/jcrsjournal.org), Jonathan Solomon (Figure S5, available at: www/jcrsjournal.org), and Sumitra Khandelwal (Figure S6, available at: www/jcrsjournal.org).

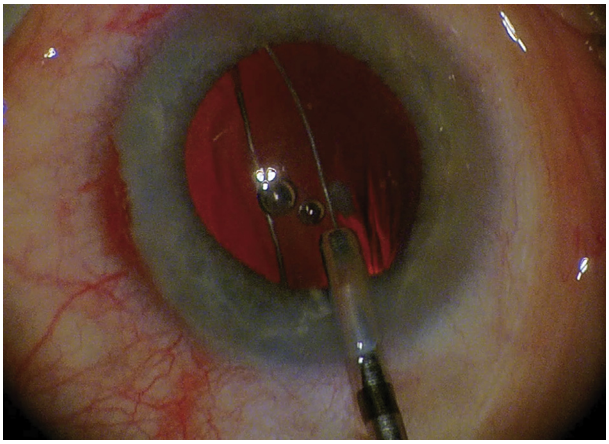

Figure 14. The loop now encircles the nucleus

Torsional Ultrasound and Dense Cataracts

The introduction of torsional and elliptical US patterns can improve the speed and efficiency of cataract emulsification. They use oscillatory motion at the phaco tip to emulsify lens material in a seamless cutting motion.[52] The side-to-side movement of the phaco tip produces minimal repulsion of lens material, resulting in improved followability, efficiency, and thermal safety.[53] Lens fragments remain close to the tip or at the tip and away from the endothelium.

In conclusion, although removing dense cataracts can be more challenging, it also can be more rewarding for both the patient and the surgeon because of the profound restoration of vision that can occur in successful cases. Careful attention to detail and technique makes a successful outcome more likely.

Table 1. Dr. Abhay R. Vasavada's US and fluidic parameters for different phases of dense cataract emulsification with an active-fluidics torsional phacoemulsification machine (Centurion, Alcon Surgical, Inc.)

Parameter	US Energy (%)*	Aspiration Flow Rate (cc/min)	Vacuum (mm Hg)	Bottle Height (cm)
Sculpting	50 to 60	20	50	50
Nuclear division	50 to 60	20	500 to 600 (depending on nuclear density)	50
Nuclear fragment removal	70 to 80	20	400, reduce to 300 during last fragment removal	90

US = ultrasound
*Burst Mode: on time 200 ms, off time 50 ms

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Disclosures: *Dr. Vasavada received a research support grant from Alcon Laboratories, Inc. Dr. Allen is a consultant to and serves on the speaker’s bureau for Alcon Laboratories, Inc. and Bausch & Lomb, Inc. None of the other authors has a financial or proprietary interest in any material or method mentioned.*