BMJ Open Ophthalmology

Surgical repair of primary non-complex rhegmatogenous retinal detachment in the modern era of small-gauge vitrectomy

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To cite: Moinuddin O, Abuzaitoun RO, Hwang MW, *et al*. Surgical repair of primary non-complex rhegmatogenous retinal detachment in the modern era of small-gauge vitrectomy. *BMJ Open Ophthalmology* 2021;**6**:e000651. doi:10.1136/bmjophth-2020-000651

Received 3 November 2020
Revised 1 February 2021
Accepted 11 February 2021

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ABSTRACT

Objective To report anatomic and visual outcomes of pars plana vitrectomy (PPV), as well as scleral buckling (SB) and PPV/SB as surgical treatments for the management of primary, non-complex rhegmatogenous retinal detachment (RRD).

Methods and analysis Data from 751 eyes that underwent PPV, SB or combined PPV/SB as a surgical treatment for primary non-complex RRD with at least 3 months of follow-up were analysed to determine rates of single surgery anatomic success (SSAS) and final anatomic success (FAS). Patients or the public were not involved in the design, conduct or reporting of this research.

Results PPV accounted for 89.0% (n=668), PPV/SB for 6.8% (n=51) and SB for 4.2% (n=32) cases. Overall SSAS (91.2% PPV, 84.3% PPV/SB, 93.8% SB; p=0.267) and FAS (96.7% PPV, 94.1% PPV/SB and 100.0% SB; p=0.221) were reported for the three surgical groups. SSAS and FAS were similar for lens status, macular detachment status and the presence or absence of inferior retinal breaks for each of the PPV, PPV/SB and SB groups.

Conclusions In this large, single institution, retrospective case series, we report surgical outcomes for patients with primary non-complex RRD managed with PPV, SB or PPV/SB in the modern era of small-gauge vitrectomy. We demonstrate that primary PPV without adjunct SB provides excellent anatomic and visual outcomes irrespective of lens status, macular involvement or pathology location.

Key message

What is already known about the subject?

- Both scleral buckling (SB) and pars plana vitrectomy (PPV) performed independently or in tandem are established treatments for the surgical management of rhegmatogenous retinal detachment (RRD).
- The advent of small-gauge vitrectomy instrumentation which affords surgeons enhanced ability to visualise and access pathology has resulted in the expansion of indications for primary PPV.
- Consequently, there exists an advancing trend towards PPV without SB among modern vitreoretinal surgeons.

What are the new findings?

- We demonstrate that meticulous small-gauge PPV yields excellent anatomic and visual outcomes regardless of lens status, macular status or location of pathology in the management of non-complex RRD.

How might these results change the focus of research or clinical practice?

- Small-gauge PPV will remain to be the primary surgical technique for the repair of non-complex RRD.

INTRODUCTION

Primary rhegmatogenous retinal detachment (RRD) is an important cause of visual morbidity worldwide, and has an annual incidence between 6 and 18 per 100 000 people.[1–4] RRD occurs when a break in the retina allows liquified vitreous to directly enter and accumulate within the subretinal space, leading to a separation of the neurosensory retina from its underlying retinal pigment epithelium.[5] Gonin first discovered that retinal breaks were the precipitating cause of RRD nearly a century ago, and further demonstrated that sealing these breaks, which he did with thermal cautery, would treat the retinal detachment.[6] Despite the vast evolution of the field of vitreoretinal surgery since then, the fundamental principles of RRD repair have remained essentially the same. The current schema of retinal detachment repair is to identify all retinal breaks, seal them with laser retinopexy or cryotherapy, and tamponade the breaks using internal or external agents in order to facilitate retinal reapposition.

Modern techniques to treat retinal detachment can be categorised as non-incisional or as incisional surgical repair modalities. Pneumatic retinopexy and laser

barricade remain viable non-incisional options in the management of select cases of RRD, but are employed far less often than incisional surgery in current vitreoretinal practice.[7 8] The two most common surgical repair modalities are pars plana vitrectomy (PPV) and scleral buckling (SB), performed independently or in tandem as a combined operation (PPV/SB).[9 10] The decision to perform PPV and/or SB is made on a case-by-case basis and is generally guided by an amalgam of factors such as surgeon preference and experience with each type of surgery, observed vitreoretinal pathology, and overall anatomy of the affected eye. SB is the more established technique with the longest published follow-up data[11] and has been successfully employed in the repair of RRD since its implementation by Custodis and Schepens *et al* almost 70 years ago.[12 13] Despite a stark decline in popularity over the past two decades in the USA after the publication of the SB versus primary vitrectomy in RRD Study (SPR Study),[9 14 15] SB continues to be favoured by many surgeons for the management of young phakic patients, especially those without posterior vitreous detachment (PVD), and by some surgeons for RRD associated with inferior breaks.[10 16 17]

PPV, in contrast, has developed an increasing role in the management of RRD since its inception by Machemer *et al*.[18] PPV has evolved generationally from a neoadjuvant procedure performed at the time of SB to the most frequently used primary treatment for retinal detachment.[9 14] The trend towards PPV without SB is supported by a growing body of literature documenting comparatively greater patient comfort, less surgically induced trauma and morbidity, reduced surgical times, and shorter periods of postoperative recovery.[19–21] The present era of vitrectomy has been accelerated by the advent of wide-angle viewing systems and small gauge instrumentation that significantly enhance surgeon ability to visualise and access pathology and avoid sclerotomy complications, and have consequently resulted in the expansion of indications for primary PPV.[22–24]

These advances in instrumentation, combined with the improved intraoperative identification of retinal breaks, can provide very high (>90.0%) single surgery success rates with PPV alone in the management of uncomplicated RRD, as exemplified in the literature for pseudophakic eyes,[25–28] which includes a previously published single surgeon series for both phakic and pseudophakic eyes from our institution.[29] In contrast, other studies report surgical anatomic success rates with PPV at just over 80%, and suggest that SB or the addition of a scleral buckle at the time of vitrectomy provides comparatively better anatomic and patient visual outcomes.[30–32]

The purpose of this retrospective, non-consecutive, interventional case series was to report the anatomic and visual outcomes in eyes with primary non-complex RRD managed with PPV, SB and PPV/SB performed by a single group of vitreoretinal surgeons in the modern era of vitrectomy. To the best of our knowledge, this study represents the numerically largest single institution case series and the longest documented follow-up on the surgical management of non-complex RRD managed with primary vitrectomy reported in the literature.

MATERIALS AND METHODS

The research was conducted in compliance with the Health Insurance Portability and Accountability Act and the Declaration of Helsinki, while abiding to all regional, national and international laws of the institution involved in this study.

Data collection

Data were obtained from patients treated at a single academic teaching hospital that regularly manages a large variety of surgical retinal cases, including a large volume of non-complex and complex RRD. Cases for review and inclusion were identified using a combination of Current Procedural Terminology billing and tracking codes, International Classification of Diseases diagnostic codes and procedural codes internal to the University of Michigan (table 1).

Data for each case were reviewed in three time-separated phases, namely preoperative, perioperative and postoperative. Patient and surgical case data were collected from text, examination findings, drawings, ophthalmic photography and diagrams sourced from office visit encounter notes, operating room notes, procedure notes and communications with referring

Table 1 Appendix of data extraction codes

Surgery/Diagnosis	ICD 10	ICD 9	CPT
Retinal detachment	H33.00, H33.01, H33.02, H33.001, H33.002, H33.009, H33.011, H33.012, H33.019, H33.021, H33.022, H33.029	361.00, 361.01, 361.02, 361.05	
Repair of retinal detachment	–	–	67101, 67105
Pars plana vitrectomy	–	–	67108, 67036, 67039, 67040
Scleral buckling	–	–	67107

CPT, Current Procedural Terminology; ICD, International Classification of Diseases.

physicians stored within the institution's electronic medical record (Epic Systems Corporation, Verona, Wisconsin, USA). Cases missing date of surgery, type of operation performed, and eye laterality data were excluded.

Case selection and assessment

Patients diagnosed with RRD that underwent surgical treatment with PPV, SB or PPV/SB between 1 January 2011 and 31 October 2019 were selectively included in this study. All cases were performed and managed by twelve vitreoretinal surgeons at the University of Michigan W.K. Kellogg Eye Center with expertise and experience regularly performing each of the three surgical techniques. In order to best assess surgical outcome and prognosis, a minimum of 90 days of documented postoperative follow-up was required for inclusion in this study.

The definition of primary non-complex RRD was determined based on a review of the existing literature[33 34] in conjunction with the clinical judgement of the investigators at the time of this study's conception. The aim was to generate a cohort of anatomically comparable cases that could be judiciously treated with PPV, SB or PPV/SB while purposefully excluding cases with characteristics predictive of a high likelihood of surgical failure or generally favouring the selection of one procedure over another. As such, the presence or history of any of the following findings in the eye undergoing surgical repair warranted exclusion from this study: penetrating or open globe injury, blunt ocular trauma within 90 days of presentation, RRD causally associated with retinovascular diseases, conditions associated with the development of exudative retinal detachment, retinal degeneration, myopic traction maculopathy, retinal dialysis, dense cataract, proliferative vitreoretinopathy (PVR), endophthalmitis, giant retinal tear, posterior staphyloma, choroidal detachment, Stickler syndrome, intraocular malignancy, intended membrane peel at the time of surgery, prior surgical or non-incisional RRD repair in the affected eye or history of intraocular surgery except cataract surgery. Additionally, patients diagnosed with RRD and managed non-surgically with pneumatic retinopexy, laser barricade or observation alone were excluded.

Retinal breaks were characterised by the number and hemispheric location, with breaks below the clock hours of 3:00 and 9:00 considered to be inferior. Retinal detachments were characterised by size determined as the total number of clock hours of detachment, and hemispheric predominance based on if the majority of the clock hours of detachment were above (superior) or below (inferior) the horizontal meridian that bisects 3:00 and 9:00. Cases that had an approximate equal number of clock hours of retinal detachment both above and below the horizontal meridian were deemed equilateral. Macular status was classified as macula-on or macula-off. Macula-on was considered as having the fovea fully attached or partially attached, while macula-off was considered as having the fovea entirely detached.

Outcome measures

The primary outcome measure of this investigation was anatomical success in patients undergoing PPV, SB or PPV/SB for the treatment of primary non-complex RRD. Anatomic success in this investigation was defined as reattachment of the retina without the identifiable presence of subretinal fluid (SRF) capable of increasing. The presence of small areas of SRF immediately posterior to a buckle was considered to be within the limits of surgical anatomic success. Anatomic success was subcategorised into single surgery anatomic success (SSAS) and final anatomic success (FAS). SSAS was defined as achieving retinal reattachment at a minimum of 3 months after a single PPV, PPV/SB or SB operation. FAS was defined as retinal reattachment at most recent follow-up that required one or more additional surgeries for recurrent retinal detachment after the initial PPV, PPV/SB or SB operation regardless of existing silicone oil tamponade. The time intervals for SSAS and FAS were considered uniformly among patients.

A secondary outcome measure was visual acuity (VA) at most recent follow-up in patients undergoing PPV, SB or PPV/SB for the treatment of primary non-complex RRD. Visual outcome was based on documented assessments of VA, VA with pinhole, or best corrected VA with refraction at follow-up. For patients in whom multiple documented assessments of VA were available at most recent follow-up, the best VA value was selected for analyses. All VA data were initially collected as Snellen VA and then converted to logMAR for statistical analyses. These outcome measures were further investigated for patients in each of the three surgical groups stratified by anatomic features at the time of presentation of retinal detachment. Specifically, anatomic and visual outcomes were reported for patients in the PPV, SB and PPV/SB groups subcategorised based on lens status, the presence or absence of inferior retinal breaks and macular detachment status.

Statistical analyses

The SPSS V.26.0 software (IBM) was used to conduct all statistical analyses. For continuous variables, the Shapiro-Wilk test of normality was used to test the distribution of data. The median was chosen as a central tendancy measure for representing non-parametric data. Range was used as the variability measure in order to highlight the important outliers in the data. Homogeneity of variance was tested using Levene's test for equality of variance. Comparisons of continuous variables were performed through testing the difference in sample means using Welch's t-test (for two groups), or the analysis of variance, followed by Tukey's post hoc testing (for three groups). For categorical variables, significant differences were analysed using the χ^2 test.

Table 2 Demographics

	Total (n=751)	PPV (n=668)	PPV/SB (n=51)	SB (n=32)	
	n (%) or median (range)	n (%) or median (range)	n (%) or median (range)	n (%) or median (range)	P value* †
Age (years)	55 (9–92)	56 (10–92)	54 (12–74)	32 (9–83)	<0.001
Male	506 (67.4%)	452 (67.7%)	32 (62.7%)	22 (68.8%)	0.759
Right eye	405 (53.9%)	362 (54.2%)	22 (43.1%)	21 (65.6%)	0.124
Follow-up (months)	22.5 (3–100)	24 (3–100)	21 (3–26)	12 (3–20)	<0.001

*P values reflect the comparison between the three surgical groups (PPV, PPV/SB and SB).
†P values <0.05 obtained by ANOVA or χ^2 test were considered statistically significant.
ANOVA, analysis of variance; PPV, pars plana vitrectomy; SB, scleral buckling.

RESULTS

Demographics

After accounting for inclusion and exclusion criteria, a total of 751 cases of primary non-complex RRD were included in this study (table 2).

All patients were managed with PPV, SB or PPV/SB as a primary treatment and had greater than or equal to 90 days of documented postoperative follow-up. The median age of patients at the time of surgery was 55 years (range, 9–92). By surgical group, the median age for patients in the PPV group was 55 (range, 19–92 years), 54 (range, 12–74 years) for patients in the PPV/SB group and 32 (range, 9–83 years) for patients in the SB group. Patients undergoing SB were significantly younger at time of surgery as compared with patients undergoing PPV (p<0.001) or PPV/SB (p<0.001). There was a greater proportion of men (67.4%) than women (32.6%). With respect to case laterality, there were 405 (53.9%) right eyes and 346 (46.1%) left eyes. PPV was the most frequently performed (89.0%) primary surgery in this cohort, followed by PPV/SB (6.8%), and SB (4.2%). The median length of postoperative follow-up for the total cohort was 22.5 months (range, 3–100 months). By surgical group, the median length of postoperative follow-up was 24 months (range, 3–100 months) for PPV, 21 months (range, 3–26 months) for PPV/SB and 12 months (range, 3–20 months) for SB.

SB was performed in 32 cases in this cohort of 751 total patients. In all cases, solid silicone or sponge-based exoplants were used. A variety of SB approaches were employed by the surgeons on a case-by-case basis, including encircling band placement with or without added segmental or radial elements, as well as segmental buckling. External drainage of SRF was performed in 25 (78.1%) patients. An intraocular gas tamponade with perfluoropropane gas (C3F8) was placed in 4 (12.5%) cases.

A combined PPV and SB surgical operation (PPV/SB) was performed in 51 cases. Similar to cases managed with SB, various SB techniques including encircling band placement, radial band placement and segmental buckling were performed on an individualised surgical case basis. With regard to the vitrectomy aspect of these combined procedures, three different PPV gauges were employed. A 25-gauge PPV was selected most frequently and was performed in 38 (74.5%) cases, followed by 23-gauge PPV performed in 12 (23.5%) cases and 20-gauge PPV performed in 1 (2.0%) case. Internal drainage through a break, retinotomy, or both was performed in 42 (82.4%) cases, and perfluorooctane (PFO) was used to facilitate drainage in 11 (21.6%) cases. Intraocular tamponade was with C3F8 in 44 (86.3%) cases, silicone oil in 5 (9.7%) cases, sulfur hexafluoride SF6 in 1 (2.0%) case and was unspecified in 1 (2.0%) case.

Primary PPV was employed in 668 cases. Similar to cases managed with PPV/SB, 25-gauge PPV was performed most frequently. A 25-gauge PPV was performed in 407 (60.9%) cases, followed by 23-gauge PPV in 257 (38.5%) cases, 20-gauge PPV in 3 (0.5%) cases, and 27-gauge PPV in only 1 (0.1%) case. Internal drainage through a break, retinotomy or both was performed in 522 (78.1%) cases, and PFO was used intraoperatively in 87 (13.0%) cases. Intraocular tamponade was with C3F8 in 618 (92.5%) cases, unspecified in 27 (4.0%) cases, air in 22 (3.3%) cases, SO in 19 (2.8%) cases and SF6 in 2 (0.3%) cases.

Surgical cases

The median size of retinal detachment for the entire patient cohort was 4.8 clock hours (table 3).

Analysed by surgical group, the median size of retinal detachment was 4.8 clock hours in patients treated with PPV, 5.6 clock hours in patients treated with PPV/SB and 4.2 clock hours in patients treated with SB. The size of retinal detachment was significantly greater in the PPV/SB group compared with the SB (p=0.008) and PPV (p=0.023) groups, but RD size in the PPV group was not significantly greater than that in the SB group (p=0.253). With regard to hemispheric predominance, approximately half (56.2%) of all retinal detachments were superior (p<0.001). There was no statistically significant difference in the distribution of superior, inferior or equilateral retinal detachments across the three surgical groups.

There was a significantly greater percentage of macula-off retinal detachments (55.4%) as compared with macula-on retinal detachments (44.6%) in the overall patient population (p=0.003). However, when analysed by subset there was no statistically significant difference

Table 3 Retinal detachment size, location, macular status, location of breaks, number of retinal breaks and lens status at time of surgery

	Total	PPV	PPV/SB	SB	
	n (%) or Median (range)	n (%) or Median (range)	n (%) or Median (range)	n (%) or Median (range)	P value*†
Size (clock hours)	4.8 (1–11)	4.8 (1–10)	5.6 (1.5–11)	4.2 (2–6)	0.007
Hemisphere					
Superior	385 (56.2%)	348 (57.3%)	19 (41.3%)	18 (56.2%)	0.313
Inferior	222 (32.4%)	192 (31.7%)	19 (41.3%)	11 (34.4%)	
Equilateral	78 (11.4%)	67 (11.0%)	8 (17.4%)	3 (9.4%)	
Macula status					
On	335 (44.6%)	303 (45.4%)	15 (29.4%)	17 (53.1%)	0.53
Off	416 (55.4%)	365 (54.6%)	36 (70.6%)	15 (46.9%)	
Break location					
Inferior	297 (39.5%)	262 (39.2%)	20 (39.2%)	15 (46.9%)	0.687
Non-inferior	454 (60.5%)	406 (60.8%)	31 (60.8%)	17 (53.1%)	
Retinal breaks					
1	293 (40.9%)	263 (41.4%)	19 (38.0%)	11 (36.7%)	0.124
2–4	208 (29.1%)	189 (29.7%)	15 (30.0%)	4 (13.3%)	
>4	215 (30.0%)	184 (28.9%)	16 (32.0%)	15 (50.0%)	
Lens status					
Phakic	441 (59.9%)	378 (57.8%)	35 (68.6%)	28 (90.3%)	0.001
Pseudophakic	295 (40.1%)	276 (42.2%)	16 (31.4%)	3 (9.7%)	

*P values reflect the comparison between the three surgical groups (PPV, PPV/SB and SB).
†P values <0.05 obtained by ANOVA or χ^2 test were considered statistically significant.
ANOVA, analysis of variance; PPV, pars plana vitrectom; SB, scleral buckling.

in the proportion of macula-off versus macula-on retinal detachments across the PPV, PPV/SB and SB groups. With respect to lens status, there was a significantly greater (p<0.001) proportion of total cases (59.9%) that were phakic at the time of presentation compared with cases that were pseudophakic (40.1%). The SB group had a significantly greater proportion of phakic cases as compared with the PPV (p<0.001) and PPV/SB (p=0.024) groups, while there was no significant difference in the proportion of phakic cases between the PPV versus the PPV/SB groups (p=0.13).

Cases were numerically categorised as having only a single retinal break, two to four retinal breaks or greater than four total retinal breaks. There was a significantly greater proportion (p<0.0001) of overall surgical cases that had a single identifiable retinal break (40.9%), as compared with the proportions of cases that had two to four breaks (29.1%) or four or more breaks (30.0%). However, there was no statistically significant difference in the distribution of cases that had a single break, two to four breaks or greater than four breaks among the three surgical groups. The majority of cases (60.5%) in this cohort did not have identifiable breaks in the inferior retina (p<0.001). Moreover, there was no statistically significant difference in the proportion of cases with inferior retinal breaks between the three surgical groups (p=0.687).

Anatomic outcomes

Total sample

For the entire cohort of 751 patients with primary non-complex RRD undergoing repair with PPV, SB or PPV/SB, SSAS was achieved in 90.8% and FAS was achieved in 96.7% of cases (table 4).

SSAS of 91.7% and FAS of 97.3% were obtained in patients presenting with macula-on retinal detachments, and 90.1% and 96.2% of patients with macula-off detachments respectively. With respect to lens status, SSAS was reported as 91.3% and FAS was reported as 96.4% in patients who had not previously undergone cataract surgery. For pseudophakic patients, SSAS and FAS were noted as 90.2% and 97.3%, respectively. In cases with at least one identified inferior retinal break, an SSAS of 88.9% and FAS of 96.0% were reported. In patients without inferior retinal breaks, SSAS of 92.1% and FAS of 97.1% were observed. There were no significant differences in single operation or final surgical success rates based on macular status, lens status at the time of surgery, the number of retinal breaks or the presence of inferior retinal breaks.

Table 4 Single surgery anatomic success and final anatomic success

	Overall	PPV	PPV/SB	SB
	n (%)	n (%)	n (%)	n (%)
SSAS				
Overall	682/751 (90.8)	609/668 (91.2)	43/51 (84.3)	30/32 (93.8)
Macula on	307/335 (91.6)	281/303 (92.7)	11/15 (73.3)	15/17 (88.2)
Macula off	375/416 (90.1)	328/365 (89.9)	32/36 (88.9)	15/15 (100.0)
Inferior breaks	264/297 (88.9)	233/262 (88.9)	17/20 (85.0)	14/15 (93.3)
Non-inferior breaks	418/454 (92.1)	376/406 (92.6)	26/31 (83.9)	16/17 (94.1)
Phakic	403/441 (91.4)	349/378 (92.3)	28/35 (80.0)	26/28 (92.9)
Pseudophakic	266/295 (90.2)	248/276 (89.9)	15/16 (93.8)	3/3 (100.0)
FAS				
Overall	726/751 (96.7)	646/668 (96.7)	48/51 (94.1)	32/32 (100.0)
Macula-on	326/335 (97.3)	295/303 (97.4)	14/15 (93.3)	17/17 (100.0)
Macula-off	400/416 (96.2)	351/365 (96.2)	34/36 (94.4)	15/15 (100.0)
Inferior breaks	285/297 (96.0)	252/262 (96.2)	18/20 (90.0)	15/15 (100.0)
Non-inferior breaks	441/454 (97.1)	394/406 (97.0)	30/31 (96.8)	17/17 (100.0)
Phakic	425/441 (96.4)	364/378 (96.3)	33/35 (94.3)	28/28 (100.0)
Pseudophakic	287/295 (97.3)	269/276 (97.5)	15/16 (93.8)	3/3 (100.0)

FAS, final anatomic success; PPV, pars plana vitrectomy; SB, scleral buckling; SSAS, single surgical anatomic success.

Pars plana vitrectomy

When PPV was selected as the single mode of repair, SSAS was reported in 91.2% of initial surgeries and FAS was ultimately achieved in 96.7% of patients. There were no significant differences in SSAS and FAS based on macular detachment status, the presence of inferior retinal breaks, total number of retinal breaks or lens status in patients treated with PPV. A subanalysis comparing 23-gauge PPV with 25-gauge PPV was performed and did not reveal statistically significant differences in SSAS and FAS overall or when controlling for macula detachment status, the presence of inferior retinal breaks, total number of retinal breaks or lens status. Cataract surgery after retinal detachment repair was performed in 221/378 (58.5%) phakic patients managed with PPV. Out of 646, nine (1.4%) patients with retinal reattachment had silicone oil tamponade in their eyes at their last follow-up examination.

Pars plana vitrectomy/scleral buckling

For patients with primary, non-complex RRD treated with combined PPV/SB, SSAS was 84.3% and FAS was achieved in 94.1% of cases. There were no significant differences in SSAS and FAS based on macular detachment status, the presence of inferior retinal breaks, total number of retinal breaks, or lens status in patients treated with PPV/SB. Similar to the PPV group, a subanalysis comparing 23-gauge PPV/SB with 25-gauge PPV/SB was performed and did not reveal statistically significant differences in SSAS and FAS overall or when controlling for macula detachment status, the presence of inferior retinal breaks, total number of retinal breaks and lens status. Cataract surgery after retinal detachment repair was performed in 24/35 (68.6%) phakic patients managed with PPV/SB. 4/48 (8.3%) patients with retinal reattachment had silicone oil tamponade in their eyes at their last follow-up examination.

Scleral buckling

In cases managed with SB alone, SSAS was reported in 98.3% of patients and FAS was achieved in all (100.0%) patients. We did not observe statistically significant differences in SSAS and FAS based on macular detachment status, the presence of inferior retinal breaks and the total number of retinal breaks. Additionally, there were no statistically significant differences in SSAS and FAS based on lens status at the time of RRD repair. Cataract surgery after retinal detachment repair was performed in 1/28 (3.6%) phakic patients managed with SB.

Visual outcomes

Postoperative VA at follow-up overall, as well as for each surgical group is listed in table 5.

In order to potentially unmask the well-established effect of vitrectomy on advancing cataract progression,[35 36] subanalyses comparing visual outcomes in phakic eyes that underwent cataract surgery postoperatively versus phakic eyes that did not undergo cataract surgery postoperatively were performed for patients in the PPV group. These analyses revealed that phakic patients undergoing cataract surgery had expectedly superior VA at follow-up ($p<0.0001$, Welch's t-test). Specifically, patients managed with PPV that later underwent cataract surgery had superior median VA (logMAR 0.097) compared with patients

Table 5 Postoperative visual outcomes (logMAR)

	Overall	PPV	PPV/SB	SB
	Median (range)	Median (range)	Median (range)	Median (range)
Overall	0.097 (–0.12 to 5)	0.097 (–0.12 to 5)	0.301 (0 to 5)	0.097 (0 to 3)
Macula on	0.097 (–0.12 to 5)	0.097 (–0.12 to 5)	0.280 (0 to 4)	0.000 (0 to 3)
Macula off	0.176 (–0.12 to 5)	0.176 (–0.12 to 5)	0.301 (0 to 5)	0.243 (0 to 0.602)
Inferior breaks	0.097 (–0.12 to 5)	0.097 (–0.12 to 5)	0.097 (0 to 3)	0.097 (0 to 3)
Non-inferior breaks	0.176 (–0.12 to 5)	0.097 (–0.12 to 4)	0.398 (0 to 5)	0.097 (0 to 0.602)
Phakic	0.097 (–0.12 to 5)	0.097 (–0.12 to 5)	0.234 (0 to 4)	0.097 (0 to 3)
Pseudophakic	0.097 (–0.12 to 5)	0.097 (–0.12 to 4)	0.398 (0 to 5)	0.176 (0 to 0.477)

PPV, pars plana vitrectomy; SB, scleral buckling.

managed with PPV that remained phakic (logMAR 0.204) at the time of follow-up. A similar subanalysis for patients treated with PPV/SB could not be performed due to the very small number of phakic patients who did not undergo cataract surgery after the combined procedure.

DISCUSSION

While excellent anatomic and functional outcomes can be achieved with PPV, SB and combined PPV/SB,[10 11 37 38] there has been a dramatic shift in the paradigm of retinal detachment repair over the last twenty years. The use of primary vitrectomy has grown to become the most commonly selected treatment for the management of RRD, while SB performed alone or as an adjunct to PPV continues to decline in popularity with each generation of newly trained vitreoretinal surgeons.[14 39–41] This unidirectional movement is attributed to the rapid evolution of the surgical landscape of vitrectomy, characterised by the improvements in small-gauge instrumentation and wide-angle viewing systems. These technologies have synergistically augmented surgeon confidence and ability to accomplish the fundamental tenets of retinal surgery as exemplified in the literature,[21 25–28] and in a previously published single surgeon case series from our institution in which SSAS and FAS were achieved in greater than 95% of eyes with non-complex RRD managed with PPV alone.[29]

The present dataset reports anatomic and visual outcomes with three different surgical techniques at a single academic institution in which PPV is the most frequently performed operation in the management of retinal detachment, during a period that encompasses the modern era of small gauge instrumentation and wide angle viewing systems. We report an SSAS of 91.7% and FAS of 96.7% in patients with non-complex RRD managed with PPV. Our findings demonstrate thorough and meticulous vitrectomy performed using small-gauge instrumentation and advanced wide-angle viewing systems is highly successful in identifying and treating all retinal breaks. Other recent studies investigating anatomic and visual outcomes with the use of PPV or SB as a primary treatment or adjunct to PPV have provided equivocal results[10 16 34 41 42] and often incomplete recommendations,[8 10 16 17 43–46] likely because the power and applicability of these studies are limited by a combination of small sample size, non-uniform diagnostic and inclusion criteria, surgeon bias, and often limited follow-up. This current investigation, with its large sample size across multiple surgeons supports the conclusion that primary vitrectomy without adjunctive SB consistently yields excellent outcomes in the treatment of non-complex RRD with various anatomic configurations in the present era of vitreoretinal surgery.

The SPR study published in 2007 remains the latest major prospective randomised controlled trial to investigate differential outcomes in the surgical management of retinal detachment. The SPR study group investigators reported that SB provides superior visual outcomes and similar anatomic outcomes in phakic eyes, and PPV provides similar visual outcomes and superior anatomic outcomes in pseudophakic eyes.[15] While the SPR study provided a wealth of critical data and the foundational framework for surgical decision making in the management of RRD, it is imperative to note that its findings and conclusions may no longer be directly applicable to modern vitreoretinal surgery. The SPR study was based on cases performed between 1998 and 2003, which predates the introduction of small gauge cannula-based instrumentation, high speed vitrectomy systems and wide-angle viewing technologies that are commonplace in vitreoretinal surgery today. This clinical trial also retained surgeon's discretion to perform supplemental SB in patients randomised to the PPV group and found that a scleral buckle was added in greater than 50% of patients undergoing vitrectomy, introducing bias and adding complexity in discerning the outcomes of primary PPV from those of PPV/SB or SB with confidence. The SPR study was furthermore restricted only to patients with moderate-complexity RRD, as this investigation was based on the principle that cases of non-complex RRD with a small number of breaks or limited extent of retinal detachment would unanimously undergo surgical repair with SB or pneumatic retinopexy. These notions reflect the surgical standard of care at that time but are not

reflective of the perspectives and practices of the modern era of PPV-dominant vitreoretinal surgery. In fact, a recent survey performed by the *American Society of Retina Specialists* in 2018 reported that vitreoretinal surgeons perform SB in less than 20% of all RRD cases.[41]

Accordingly, our analysis found that primary vitrectomy is the most frequently performed surgery in the repair of non-complex RRD overall at our institution, and also when controlling for lens status, macular detachment, and the number as well as location of retinal breaks. In contrast to the SPR study, the excellent anatomic outcomes and correspondingly favourable visual outcomes in both phakic and pseudophakic eyes managed with vitrectomy alone in the present investigation are likely attributable to the assimilation of modern small-gauge instrumentation and panoramic viewing technologies that have cumulatively enhanced the ability to view, access, and effectively treat peripheral retinal pathology, compared with the PPV systems used at the time of the SPR study. However, SB may be a superior surgical choice in a select subset of patients. Specifically, the interrelated findings that patients in the SB group were significantly younger and less likely to have undergone cataract surgery support the notion that SB is still preferable in younger phakic eyes—in particular, those without pre-existing PVD.

The Primary Retinal Detachment Outcomes Study (PROS) is another retrospective interventional case series investigating surgical outcomes in RRD repair and is the largest recently published study on the subject. Based on an analysis of cases performed in 2015, the investigators report high rates of retinal reapposition in patients managed with SB (91.2%) or PPV/SB (90.2%), but notably report a lower SSAS of 84.2% in patients managed with PPV alone. The precise reason for this discrepancy in anatomic success with primary PPV between the PROS and the present study remains unknown.

Retinal breaks below the clock hours of 3:00 and 9:00 were present in 39.5% of our patients, and we do not report a significant difference in the proportion of cases with inferior breaks between the PPV, SB and PPV/SB groups. Despite that inferior breaks may pose a greater challenge to surgical repair[47 and that supplemental SB may provide added support to the inferior vitreous base,[48 we find vitrectomy still remains the most frequently performed operation in this subset of patients with non-complex RRD. Moreover, the high rates of SSAS (88.9%) and FAS (96.2%) reported in the management of RRD characterised by inferior breaks using primary PPV reinforce our conclusion that small-gauge vitrectomy alone provides excellent anatomic success.

The rationale among some surgeons for performing combined vitrectomy with SB is rooted in the premise that placement of a scleral exoplant reduces vitreous traction in the peripheral retina, and can facilitate the closure of unidentified breaks or secondary breaks that may otherwise precipitate surgical failure.[49–51 In addition to the presence of inferior retinal breaks, greater extent of retinal detachment is sometimes considered an indication for adjunct SB as demonstrated in both PROS and the present investigation. However, even when controlling for the size of retinal detachment or macular detachment status in both phakic and pseudophakic patients, we find that PPV alone continues to yield excellent rates of primary and final surgical anatomic success that are similar to the rates observed in patients managed with PPV/SB.

Unsurprisingly, we find that visual outcomes correspond to excellent anatomic outcomes with PPV in our study population. Similar to the SB and PPV/SB groups, patients managed with primary vitrectomy demonstrated excellent VA at follow-up even when controlling for anatomic features of retinal detachment that are traditionally considered to be more challenging to repair, including macular involvement, the presence of inferior breaks and a larger area of retinal detachment. While comparitive statistical analyses are not presented due to the much smaller number of cases managed with SB or PPV/SB, the favourable visual outcomes reported in cases with a wide variety of anatomic configurations managed with PPV alone suggest that adjunct SB may provide neither added anatomic nor visual benefit.

In interpreting the many findings and conclusions presented herein, it is important to acknowledge the limitations of this investigation. In light of its retrospective basis and the non-consecutive selection of cases, this study is inherently subject to selection bias and non-randomisation, as well as a lack of standardisation in methodologies and criteria used to assess patient outcomes. Another pertinent limitation is the notable predominance of PPV in this cohort, which is attributable to vitrectomy being the most commonly selected mode of retinal detachment repair at our institution, and the much smaller number of cases managed with SB or PPV/SB which prevented the investigators from performing robust statistical analyses.

In this context, there are also several unique strengths to this investigation. Primarily, given the complex and variable nature of this condition, it is difficult to recruit an equally large sample size of patients undergoing surgical treatment for participation in a prospective clinical trial. It may furthermore not be feasible to closely follow and monitor such a large cohort of patients for a correspondingly lengthy period of time, as performed in this study. Another strength of this study is that all operations were performed by the same group of surgeons at a single institution that are experienced in performing and teaching all three surgical approaches. While this study was composed entirely of non-complex RRD cases that can be justifiably managed with PPV, SB or PPV/SB, there likely exists some degree of inherent bias in procedure choice based on each surgeon's training, preferences, and past experiences with each operation. While every effort was made to generate an anatomically comparable cohort during the design of this study, some cases may inevitably have been considered to be more complex which may

have influenced the surgeon's choice of operation. This rationale is supported by the fact that patients managed with SB were significantly younger than those managed with vitrectomy, the median size of RD was greatest in patients managed with PPV/SB, as well as the findings that PPV/SB was performed less often than primary vitrectomy and that silicone oil was used more often in PPV/SB cases which in tandem suggest that adjunct SB may have been performed in more complicated cases of non-complex RRD. We further acknowledge that retinal specialists choose the operation to be performed on a case-by-case basis at the time of evaluation of each patient, and that surgical preferences and practices may change. Surgical selection bias was further minimised as data collection and analysis were performed without prior knowledge of surgeon, surgery type, or anatomic or visual outcome.

In conclusion, PPV has become the most commonly selected and most frequently performed treatment in the surgical management of non-complex RRD.[9 14 37] The trend away from SB and towards PPV has been driven by the advent of small-gauge instrumentation and wide-angle viewing systems. Over the past 20 years, these technologies have greatly enhanced the ability to identify, access, and treat retinal pathology, such that PPV in the present era is the ideal treatment choice for an expanding number of indications in the surgical management of retinal detachment.[40 42] SB and PPV/SB are excellent surgical options, and remain invaluable in the current paradigm of retinal detachment repair. Given the differences in sample size between the three surgical groups, the goal of this investigation was not to directly compare outcomes between PPV, SB, and PPV/SB. Rather, our large retrospective study provides a wealth of data exemplifying small-gauge PPV alone is capable of providing high rates of anatomic and functional success in primary, non-complex RRD. Given the excellent single operation and FAS rates presented herein, we maintain that a minimalist approach with vitrectomy alone is ideal as it minimises cost, operation time and the potential for added patient morbidity without compromising visual outcomes in the surgical management of non-complex RRD.

Contributors All listed authors have made substantial contributions to the conception and design of this investigation, data acquisition, interpretation of statistical analyses, and/or the drafting or critical revising of the manuscript text.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests 'Yes, there are competing interests for one or more authors and I have provided a Competing Interests statement in my manuscript and in the box below'

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not required.

Ethics approval This study was approved by the Institutional Review Board of the University of Michigan (Ann Arbor, Michigan, USA) and is in concordance with the tenets of the institution's ethics committee.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon request.

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