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Comparison oftheefficacy andinvasiveness ofmanualandautomated gonioscopy

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Abstract

**Purpose** Tocomparetheefficacyandinvasivenessofmanualgonioscopyandautomated360-degreegonioscopy.

**Method** Manualandautomatedgonioscopywereperformedon70patientswithglaucoma.Manual gonioscopywasperformedbyaglaucomaspecialistandanophthalmologyresident,and automatedgonioscopy(GS-1)wasperformedbyorthoptists.Wecomparedtheexamination timeforacquiringgonioscopicimages(GS-1: 16directions;manualgonioscopy:8direc-tions).Furthermore,wecomparedthepainanddiscomfortscoresduringtheexamination usingtheIndividualizedNumericRatingScale.Amongtheimagesacquiredbyautomated gonioscopy,wealsoevaluatedthepercentagesofacquiredimagesthatcouldbeusedto determinetheangleopeningcondition.

**Results** Theexaminationtimewasnotsignificantlydifferentbetweenmanual(80.2±28.7)andauto-matedgonioscopy(94.7±82.8)(p=0.105).Thepainscoreofautomatedgonioscopy(0.22 ±0.59)wassignificantlylowerthanthatofmanualgonioscopy(0.55±1.11)(p=0.025).The discomfortscorewasnotsignificantlydifferentbetweenmanual(1.34±1.90)andautomated gonioscopy(1.06±1.50)(p=0.165).Automatedgonioscopysuccessfullyacquiredclear gonioscopicimagesin93.4%ofthetotalimages.

**Conclusion** Automatedgonioscopyiscomparableinexaminationtimeandinvasivenesstomanual

gonioscopyandmaybeusefulfor360-degreeiridocornealangleevaluation.

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PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Introduction**

Gonioscopy wasdeveloped inthe1800s[1]and isessentialforglaucomaexamination. Inthe evaluationofglaucoma, itisnecessarytodifferentiate open-angleglaucomafrom closureglau-coma[2,3].Sinceangle-closureglaucomaismorecommoninAsians,including Japanese, thaninEuropeans [4], gonioscopy ishighlyimportant inAsian countries.

Manual gonioscopy isuseful inbothdynamic andstaticexamination [5]. However,there areseveral issues,such asthelearning curveofmanualgonioscopy anddisagreement between inter-andintra-observer agreement [5,6].Because gonioscopy requiresdirectcontactwith thecorneaand itisdifficulttoacquireprecise360-degree gonioscopic images,reports sug-gestedthatgonioscopic examination isnotperformedofteninophthalmology clinical settings [7,8].

As alternativestogonioscopy, anteriorsegment opticalcoherencetomography (AS-OCT) andultrasound biomicroscopy (UBM) canbeperformed noninvasivelyand havebeenfound tobeusefulintheevaluationofiridocorneal angle structures[9–12].Inparticular, AS-OCT appearstobehighlyusefulbecause ofitsshortexamination time. However,AS-OCT and UBMcannotevaluatetrabecular meshwork pigmentation ordifferentiate whetherangle clo-sureisorganicorfunctional. Ithasbeenreported thatAS-OCTtendstoidentifyangleclosures morefrequentlythangonioscopic examination [12–14] butmaynotmatch thefindingsof gonioscopic examination inacertainnumberofcases[13,15]; therefore,ithasyetto completely replacegonioscopic examination.

AGS-1gonioscope camera(NIDEK Co.Gamagori,Japan)wasabletoacquire360-degree gonioscopic photographs automatically. Although theexamination timeofGS-1andthequal-ityoftheGS-1images havebeenreportedpreviously [16–18],thereisapaucity ofinformation onthecomparison oftheefficacybetween manualgonioscopy andGS-1.

Inthisstudy, wecomparedtheexamination timeand invasiveness betweenautomated gonioscopy performedbyorthoptists andmanual gonioscopy performedbyaglaucomaspe-cialistandanophthalmology resident. Inaddition,weevaluated thequalityoftheacquired photographsbyautomated gonioscopy andthelearning curveoftheautomated gonioscopic examination.

**Materialsandmethods** **Patientandstudydesign**

Thestudy groupincluded 70glaucomapatientswhovisited theglaucomaoutpatient clinicof theChukyoEyeClinicfromJune2019toJune2020.AllpatientswereJapanese.Thepatients hadalreadyundergone gonioscopy severaltimes beforeparticipating inthestudy.

Manual gonioscopy wasperformed byaglaucomaspecialist (M.W.)andanophthalmology resident(Y.T.).Automated gonioscopy andaquestionnaire wereadministered immediately aftertheexamination. Automated gonioscopy (GS-1)wasperformedbyorthoptists.The gonioscopic examination timewasdefinedasthedurationfromthetimethegonioscope touchedthecorneatotheendoftheexamination.

Weadministered aquestionnaire regardingpain anddiscomfort duringtheexamination andcompared theexamination timeandsubjectivescores betweenmanual gonioscopy and GS-1.Inaddition,weevaluated thequalityofthephotographsacquiredusing automated gonioscopy.

Theinstitutional reviewboardoftheChukyoEye Clinicapprovedtheresearchprotocol (20190424–01). Writteninformed consentwasobtainedfromallpatients. Thisstudyadhered tothetenetsoftheDeclaration ofHelsinki.

PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 2/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Manualgonioscopy**

Afterapplying0.4%oxybuprocaine eyedrops(Benoxil ophthalmic solution,Santen,Osaka), a gonioscope wasappliedtothecornea.Weacquiredgonioscopic photographs ineightdirec-tions(nasal, temporal,superior, inferior, nasal-superior, nasal-inferior, temporal-superior, temporal-inferior) with theattached cameraoftheslitlamp(THD-341F, 410000pixels, Ike-gamiTsushinki Co.Ltd.,Osaka). Wemeasured theexamination timeusingstopwatches to acquiregonioscopic photographs ineight directions.WeusedaSussman four-mirror hand-heldgonioscope largering(OcularInstruments, Bellevue,WA)anddidnotusehydroxyethyl cellulose(Scopizol, Senju,Osaka).

**Automatedgonioscopy(GS-1)**

Automated gonioscopy (GS-1)examinations wereperformed byfourorthoptists.Afterapply-inganestheticeyedrops, GS-1wasappliedtothecornea.Wemeasured theexamination time byusing stopwatchestoacquireGS-1photographsafterGS-1touched theeyes.Furthermore, weclassified thequalityoftheacquiredphotographs ofautomated gonioscopy:Grade0,clear andfocusedimages thatenable easyidentification oftheanglestructure; Grade1,imageswere slightlyblurred butstillallowedforidentification oftheanglestructure;andGrade2,blurred imagesthatmakeitdifficulttoidentifytheanglestructure.

**Evaluationofpainanddiscomfortscores**

Wecomparedthepain anddiscomfort scoresduring manualgonioscopy andGS-1examina-tions.UsingtheIndividualized Numeric Rating(INR) scale,eachitemwasscoredfrom 0(no pain/discomfort) to10(veryunbearable pain/discomfort).

**Comparisonofmanualandautomatedgonioscopy**

Manualgonioscopy wasperformedbyaglaucomaspecialist (M.W.)withmorethan15years ofexperience andanophthalmology resident(Y.T.) with3yearsofexperience. Thirty-six patientswereexamined byM.W.,andtheremaining 34patientsbyY.T.GS-1wasperformed byfourorthoptists withvaryingyears ofexperience.Theexamination time,pain score,and discomfortscoreobtained bytheglaucoma specialist,ophthalmology resident, andorthoptists werecompared.

**Evaluationofthelearningcurveofautomatedgonioscopy**

ToevaluatethelearningcurveofGS-1, wecompared theexamination time,pain anddiscom-fortscoresofGS-1betweenthefirstandlasttencasesthatwereexamined bythesame orthop-tistwhoperformedGS-1formorethan30cases.Inaddition,wecompared theclinical characteristics between thetwogroups,forwhichtheexamination lastedfor1min orlonger (longtimegroup)andless than1min(short timegroup).

**Statisticalanalysis**

TheMann-Whitney testwasperformed tocompare theparameters obtainedbytheglaucoma specialist,ophthalmology resident,andorthoptists. Thecorrelation betweentheexamination timeofGS-1andclinical characteristics wasanalyzedusing Pearson’stest. Thet-testwasused tocomparetheparameters betweenthegroups inwhichtheexamination timeofGS-1was1 minorlongerand lessthan1min.Statistical analyses wereperformedusing Prism5(Graph-PadSoftware, SanDiego,CA) andExcel2016(Microsoft, Washington, DC).Ap-valueofless than5%wasconsideredstatistically significant.

PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 3/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Results**

Thestudy groupincluded 70glaucomapatients. Table1showsthepatients’ demographic characteristics. Themeanpatientagewas66.8±12.1years, 38(54.3%) werewomen, theright eyewasexaminedin65.7%(46eyes)ofthecases,and 74.3%(52eyes)ofthecaseswerephakic. Figs1and2showimagesofanexamination using GS-1and itstypical results,respectively.

**Learningcurveforautomatedgonioscopyevaluation**

Wecomparedtheexamination timeofautomated gonioscopy betweenthefirstandlast ten cases.Theexamination timeofthelasttencases(75.0±91.9s)wassignificantly shorter than thefirst tencases(101.0±85.3 s)(p=0.048).

**Comparisonofautomatedgonioscopyandmanualgonioscopy**

Theresults ofthecomparison betweenmanual andautomated gonioscopy arepresented in Table2.Theexamination timewasnotsignificantly different betweenmanual (80.2±28.7 s) andautomated gonioscopy (94.7±82.8seconds) (p=0.105).Thepain score(0.22±0.59s)of automated gonioscopy wassignificantly lowerthanthatofmanual gonioscopy (0.55±1.11pts) (p=0.025).Thediscomfort scorewasnotsignificantly different betweenmanual (1.34±1.90 pts)andautomated gonioscopy (1.06±1.50pts) (p=0.165).

**Comparisonofexaminationtime**

Wecomparedtheexamination timebetween manualgonioscopy bytheexaminer andauto-matedgonioscopy, asshowninFig3.Theexamination timefortheglaucomaspecialist (60.0

**Table1.** **Demographicsofthepatients.**

|  |  |
| --- | --- |
| **Characteristics** | **Total** **(n** **=** **70)** |
| Age, years | 66.8±12.1 |
| Sex (female,male), number(%) | Female:38 (54.3%),male: 32 (45.7%) |
| Numberof right eyes (%) | 46 (65.7%) |
| Lensstatus, numberof phakic eyes (%) | 52 (74.3%) |

Examined eye

|  |  |
| --- | --- |
| Best**-**corrected visualacuity (logMAR) | 0.097±0.24 |
| Intraocular pressure (mmHg) | 16.6±5.9 |
| Visualfield, meandeviation (dB) | -11.6±7.8 |
| Spherical equivalent (D) | -2.9±3.8 |

Non-examined eye

|  |  |
| --- | --- |
| Best**-**corrected visualacuity (logMAR) | 0.067±0.29 |
| Intraocular pressure (mmHg) | 16.1±6.1 |
| Visualfield, meandeviation (dB) | -10.1±9.6 |
| Spherical equivalent (D) | -2.7±3.7 |
| Typeof glaucoma |  |
| POAG,numberof patients (%) | 41 (58.6%) |
| PACG, numberof patients (%) | 5 (7.1%) |
| SOAG, numberof patients (%) | 24 (34.3%) |

logMAR: the logarithmof the minimumangle of resolution,D: diopter, POAG:primary open-angle glaucoma, PACG:primary angle-closure glaucoma, SOAG:secondaryopen-angle glaucoma. The valuesare mean ± standard deviation.

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PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Fig1.** **TheimagesduringaGS-1examination.**PanelAshowsthemonitorofGS-1duringtheexamination.Thescreendisplaysangleimagesinfour directionsinreal-time,allowingtheexaminertocheckwhethertheimageisinfocus.PanelBshowstheGS-1examinationfromtheside.Lensesarelargeand requireawideopeningoftheeyelids.

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**Fig2.** **RepresentativeGS-1gonioscopicimagesinnormaleyes.**High-qualitygonioscopicimagesin16directionsare shown.

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PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 5/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Table2.** **Comparisonoftheexaminationtime,painscore,anddiscomfortscorebetweenmanualgonioscopyand** **automatedgonioscopy(GS-1).**

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Manualgonioscopy** | **GS-1** | **p-value** |
| **Examination** **time** **(s)** | 80.2±28.9 (CV: 0.36) | 94.7±83.5(CV: 0.87) | 0.079 |
| **Pain** **score** **(points)** | 0.55±1.11 (CV: 2.02) | 0.22±0.59(CV: 2.70) | 0.053 |
| **Discomfort** **score(points)** | 1.34±1.90 (CV: 1.42) | 1.06±1.50(CV: 1.42) | 0.49 |

CV:coefficientof variation

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±15.0s)wasshorterthanthatfortheophthalmology resident(101.5±23.9, p*<*0.0001)and automated gonioscopy (94.7±82.8s,p=0.0168).Therewasnosignificant difference inexami-nationtimebetweentheophthalmology residentandautomated gonioscopy (p=0.65).

**Comparisonofpainscores**

Wecomparedthepain scorebetweenmanual gonioscopy bytheexaminer andautomated gonioscopy (Fig4).Thepain scoresinevaluations bytheglaucomaspecialist,ophthalmology resident, andautomated gonioscopy were0.24±0.61,0.88±1.39,and0.22±0.59,respectively. Thepain scoresfortheglaucomaspecialist examinations weresignificantly lowerthanthose fortheophthalmology residentexaminations (p=0.026).Inaddition,thepainscores forthe automated gonioscopy weresignificantly lowerthanthatfortheophthalmology resident examinations(p=0.0037).Therewasnosignificantdifferenceinpainscoresbetweentheglau-comaspecialistand automated gonioscopyevaluations (p=0.80).

**Fig3.** **Analysisoftheexaminationtimebetweentheglaucomaspecialist,ophthalmologyresident,andautomatedgonioscopy.**\*,\*\*,and\*\*\*represent p*<*0.05,p*<*0.01,andp*<*0.001,respectively.nsrepresentsstatisticallynotsignificant.

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PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Fig4.** **Comparisonofthepainscoresduringexaminationsbetweentheglaucomaspecialist,ophthalmologyresident,andautomatedgonioscopy.**\*,\*\*, and\*\*\*representp*<*0.05,*<*0.01,and*<*0.001,respectively.nsrepresentsstatisticallynotsignificant.

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**Comparisonofdiscomfortscores**

Wecomparedthediscomfortscoresbetweenmanualgonioscopy bytheexaminerandauto-matedgonioscopy,asshowninFig5.Thediscomfortscoresinevaluationsbytheglaucomaspe-cialist,ophthalmology resident,andautomatedgonioscopywere0.61±1.19,2.22±2.19,and1.06 ±1.50,respectively.Thediscomfortscoresfortheglaucomaspecialistexaminationsweresignifi-cantlylowerthanthosefortheophthalmologyresidentexaminations(p=0.0003).Inaddition, discomfortscoresinautomatedgonioscopyweresignificantlylowerthanthoseinophthalmol-ogyresidentexaminations(p=0.0078).Therewasnosignificantdifferenceindiscomfortscores betweentheglaucomaspecialistandautomatedgonioscopyevaluations(p=0.11).

**Qualityassessmentofautomatedgonioscopyimages**

Therewereatotalof1120automated gonioscopy photographs. Among them,986imageswere definedasGrade0(clearandfocused), 60asGrade1(slightly blurred),and74asGrade2 (blurred).Ofallimages,93.4%wereGrade0or1.

**Evaluationofthefactorsinfluencingtheexaminationtimeofautomated** **gonioscopy**

Thecorrelation betweentheexamination timeofautomated gonioscopy andvisualacuity, visualfield,and refractiveerroroftheexamined andnon-examined eyeswereanalyzed (Table3).Examination timeshowed alowpositivecorrelation withvisualacuityintheexam-inedeye(r=0.24,p=0.043).Inaddition,wecompared theclinical characteristics between the long-andshort-time groups (Table 4).Therewerenosignificant differencesbetween thetwo groups.

PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 7/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Fig5.** **Analysisofthediscomfortscoresintheexaminationsbytheglaucomaspecialist,ophthalmologyresident,andautomatedgonioscopy.**\*,\*\*,and \*\*\*representp*<*0.05,*<*0.01,and*<*0.001,respectively.nsrepresentsstatisticallynotsignificant.

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**Discussion**

Gonioscopy isessentialforglaucomaexamination. However,theuseofgonioscopy islimited becauseofthecomplexityoftheexaminationandtheskillsrequired.Gonioscopyisaninvasive examination becauseitneedstotouchthecornea directly.Inaddition, itisdifficulttoacquire precise360-degreegonioscopic imagesusing manualgonioscopy. GS-1canacquire

**Table3.** **CorrelationbetweentheexaminationtimeofGS-1andclinicalcharacteristicsofthepatients.**

|  |  |  |
| --- | --- | --- |
| **Characteristics** | **Correlation** | **p-value** |
| Examined eye |  |  |
| Best**-**corrected visual acuity (logMAR) | 0.24 | 0.043 |
| Intraocular pressure(mmHg) | -0.058 | 0.64 |
| Visual field, meandeviation (dB) | -0.18 | 0.15 |
| Spherical equivalent refractive error, diopters (D) | 0.15 | 0.23 |
| Non-examined eye |  |  |
| Best**-**corrected visual acuity (logMAR) | 0.0014 | 0.99 |
| Intraocular pressure(mmHg) | -0.13 | 0.29 |
| Visual field, meandeviation (dB) | -0.056 | 0.65 |
| Spherical equivalent refractive error, diopters (D) | 0.048 | 0.47 |

logMAR: the logarithmof the minimumangle of resolution

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PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 8/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

**Table4.** **Subgroupcomparisonofclinicalcharacteristicsofthepatientsbetweenexaminationslastedfor***<***1minand**�**1min.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Characteristics** | **Examination** **time:** *<* **1** **min** | **Examinationtime:** � **1** **min** | **p-value** |

Examined eye

|  |  |  |  |
| --- | --- | --- | --- |
| Best**-**corrected visual acuity (logMAR) | 0.081±0.20 | 0.13±0.30 | 0.42 |
| Intraocular pressure (mmHg) | 16.5±5.2 | 16.5±6.9 | 0.97 |
| Visualfield, meandeviation (dB) | -10.9±7.9 | -13.0±7.7 | 0.35 |
| Sphericalequivalent refractiveerror,diopters (D) | -3.1±4.1 | -2.4±3.4 | 0.47 |

Non-examined eye

|  |  |  |  |
| --- | --- | --- | --- |
| Best**-**corrected visual acuity (logMAR) | 0.033±0.20 | 0.13±0.4 | 0.20 |
| Intraocular pressure (mmHg) | 16.0±3.4 | 16.0±8.9 | 0.96 |
| Visualfield, meandeviation (dB) | -10.7±10.0 | -9.1±8.9 | 0.57 |
| Sphericalequivalent refractiveerror,diopters (D) | -2.8±4.0 | -2.6±3.2 | 0.86 |

logMAR:the logarithm of the minimumangle of resolution. Thevalues are mean± standarddeviation.

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360-degreegonioscopic images automaticallyand completetheexamination inashorttime [17].However,tothebest ofourknowledge, nostudies haveevaluated pain anddiscomfort duringautomated gonioscopy. Inthis study,wecompared theexamination timeandinvasive-nessbetween automated andmanual gonioscopy. Moreover, thelearning curveofautomated gonioscopy wasevaluated.

Inourstudy,automated gonioscopy lasted94.7±83.5s.However,inaprevious report[17], automated gonioscopy wasreported totakeapproximately 20sfromGS-1touchingtheeyes totheacquisition oftheautomated gonioscopy photographs. Thisdiscrepancy inthestudy resultsmaybebecause ourstudyincluded manycasesofadvancedglaucoma, which required moreexamination timeduetopoor eyefixation. Inthepreviousstudy, theauthors performed pre-trainingforapproximately oneweek,whichmight haveaffected theexamination timeand maybeanotherreason fortheshorter examination timeintheirstudy.Inourstudy,therewas asignificant trendtowardshorter examination timesinthelatterhalfofGS-1examinations by thesameexaminer, suggestingtheexistenceofalearning curveinthetest.

Although therewasnosignificant difference inmeasurement timebetween automated and manual gonioscopy, automated gonioscopy showedalargerdeviation inexamination time. Thedeviationofexaminationtimeformanualgonioscopywas28.9s,withacoefficientofvari-ationof0.36,which wasnotlarge,anditwasassumedthatallcases,including thosewithpoor eyefixation, couldbeexaminedinasimilar amountoftime.Ontheotherhand,thedeviation ofexamination timeforautomated gonioscopy was83.5s,withalargercoefficient ofvariation of0.87,whichsuggested thatautomated gonioscopy hadalargevariation inexamination time dependingontheeyefixationcondition. Manualgonioscopy cancontroltheposition ofthe eyeballbecause thegonioscope isindirectcontactwiththeeye;therefore,theexamination timeofmanualgonioscopy fluctuated littleand wasgenerallyperformed inapproximately the sameduration. However,automated gonioscopy cannotcontroltheposition oftheeyeballs andreliesontheexaminer’s fixation effort,which isassumedtobethereason forthelarge fluctuation intheexamination time.

Theexamination time,pain score,and discomfortscoreweresignificantly loweringlau-comaspecialistexaminations thaninophthalmology residentexaminations. Itwasassumed thattheglaucomaspecialistwasmoreproficient inmanualgonioscopy, whichallowed himto performtheexamination inashortertimeandlessinvasively. Thissuggests thattheexamin-er’sexperience and skillsaffectmanual gonioscopy. Regardingthecomparison betweenthe glaucomaspecialist andautomated gonioscopy, onlytheexamination timewasshorterin

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PLOS ONE Clinicalefficacyofautomatedgonioscopy

glaucomaspecialist examinations. Inthecomparison betweentheophthalmology residentand automated gonioscopy examinations, whiletheexamination timewasnotsignificantly differ-ent,thepainanddiscomfort scoresweresignificantly lowerinautomated gonioscopy. This suggeststhatautomated gonioscopy canbeperformed inashortertimeandislessinvasive thanwhenperformedbyinexperienced ophthalmologists. Inaddition,automated gonioscopy requiresmoreexamination timethanglaucomaspecialists and canbeperformed withthe samelevelofinvasiveness. Automated gonioscopy canpreventfurther pressuretotheeyeonce acertainamountofpressureisappliedtothelens,whichmightleadtolowerpainanddiscom-fortscoresthaninmanual gonioscopy. Inthisstudy,weused agonioscope without flanges. Manualgonioscopy with aflangedgonioscope requires hydroxyethylcellulose,which may causehigher levelsofdiscomforttotheexaminee. This suggeststhatGS-1islessinvasivethan manual gonioscopy.

Previous studies[16–19] haveshown thatitisdifficult toidentifyanglestructuresin 3–36.8%ofimagestakenbyautomated gonioscopy. Inourstudy,only74pictures (6.6%)were categorized asblurredimages.Thisresultwasthesameasorslightlybetter thanthose reported byprevious studies [16,19].Weinstructed ouroptometrists toacquireimages onlyafterthe anglestructurewasconfirmed atthetimeofacquisition, whichmighthave ledtomorelegible images.

Weevaluated thecorrelation betweenclinical characteristics, suchasvisualacuityand visualfield,inindividualcasesand theexamination timeofautomated gonioscopy. Theresults showedasignificant positive correlationonlyforvisualacuityintheexaminedeyes.Further-more,therewerenosignificant differences inother clinicalcharacteristics betweenthelong-andshort-time groups.Theseresults suggestthatbettervisualacuityintheexamined eye mighthaveledtobetter eyefixationand ashorterexamination time.

TheEyeCam(ClarityMedical Systems, Pleasanton, GA)canobtain gonioscopic images similar tothose obtainedbyautomated gonioscopy. EyeCamhas beenreported tobeasuseful asgonioscopy indetectingangle closures[20,21],and theresultsappear tobecomparable for thedetection ofangleclosureswithGS-1[19].However,althoughEyeCam isminimally inva-sive,theexamination timeofEyeCamwasreported tobe5–10min/eye[20]. Therefore,auto-matedgonioscopy, whichcompletes theexamination inaboutonemin,isconsidered more clinicallyuseful thanEyeCam. Acomparative studyisneededinthefuture.

Automated gonioscopyallowsgonioscopic imagestobeobtainedquickly andminimally invasively.However,GS-1hasseveral limitations. Automated gonioscopy cannotperform dynamic examinations, including compression. Therefore, therearesomecasesinwhichitis notpossible todeterminewhethertheanglestructurecanbejudgedduetoanangleclosureor poorimage qualityusing onlyautomated gonioscopy. Inaddition, somepatientswithpoor eyefixationordifficultyinmaintainingposturecannotundergoautomatedgonioscopyexami-nations.Thesefindings suggest thatautomated gonioscopyisnotacompletereplacementfor manual gonioscopy. Manual gonioscopy providesamoredetailedviewoftheangular struc-ture.Ontheotherhand,automated gonioscopy cantake360-degreegonioscopic images, whichmaybeuseful forevaluating thechangesovertime, especially aftersurgerysuchastra-beculotomyandtrabeculectomy, andforscreening forangleclosure.

Therearesomelimitations tothis study.First, thepatientshadalreadyundergone gonio-scopyseveraltimes beforeparticipating inthestudy.Ifonlycaseswithnohistoryofgonio-scopyhadbeenconsidered,discomfort andpainscores mayhavebeensimilarbetween automated andmanual gonioscopy owingtothelack ofexperience ofinvasiveexamination withinstrumentation touchingtheocularsurface. Ahistory ofgonioscopyexamination isa confounding factor,andfurtherstudyinpatientswith nohistoryofgonioscopy iswarranted. Second,wedidnotevaluatethelearningcurveassociated with manualgonioscopy. The

PLOSONE|<https://doi.org/10.1371/journal.pone.0284098>April6,2023 10/12

PLOS ONE Clinicalefficacyofautomatedgonioscopy

comparison ofthelearningcurvebetween automated gonioscopy andmanual gonioscopyis alsonecessarytoassesstheutilityofautomated gonioscopy infuturestudies.Third,manual gonioscopy wasperformed byaglaucoma specialistandophthalmology residentwhile,auto-matedgonioscopy wasperformedbyorthoptists inthisstudy.Thesewereconductedwiththe assumption ofactualusersinJapan.Thesubjective factorssuchaspain anddiscomfortare likelytobeinfluenced bytheexaminer’s technique. Toavoidthisbias,adetailedexamination ofalargenumberofcaseswould benecessaryinthefuture.Furthermore,theremightbebias duetotheorderofexaminations because allcaseswereexaminedfirstbymanual gonioscopy andthenbyautomated gonioscopy.

Inconclusion, thecurrentstudyshowedthatautomated gonioscopy isperformedwitha similar levelofinvasiveness andexamination timeasglaucomaspecialists. Thismay improve thequalityofglaucomatreatment andresearchbecause automated gonioscopy enablesusto compareangle structuresovertimebyacquiring 360-degreegonioscopic images.

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