Research Article

Cuestiones de Fisioterapia

Medicine

COMPARISON OF INTRAOCULAR PRESSURE MEASURED BY NON-CONTACT TONOMETRY AND GOLDMANN APPLANATION TONOMETRY IN ADULTS: A HOSPITAL-BASED CROSS-SECTIONAL STUDY

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Abstract

Background: Accurate measurement of intraocular pressure (IOP) is central to the detection and management of glaucoma. Goldmann applanation tonometry (GAT) remains the reference standard, but its requirement for corneal contact, topical anaesthesia and fluorescein, together with a theoretical risk of cross-infection, has prompted interest in non-contact tonometry (NCT) as a screening alternative. Agreement data from South Indian populations are limited. Objective: To assess the agreement between IOP measured by NCT and GAT in adult patients attending a tertiary care teaching hospital in South India. Methods: In this hospital-based cross-sectional method-comparison study, 200 adults underwent IOP measurement by NCT and GAT in the same sitting. The per-patient mean of both eyes was used for analysis. Agreement was evaluated using the paired t-test, Pearson correlation, the intraclass correlation coefficient (ICC) and Bland–Altman limits of agreement, with statistical significance set at $p<0.05$. Results: The mean age was 52.6 (SD 18.2) years; 109 (54.5%) were men. Mean IOP was 17.47 (SD 2.78) mmHg by NCT and 17.54 (SD 2.89) mmHg by GAT. The mean difference (NCT − GAT) was −0.07 mmHg (SD 0.83), with 95% limits of agreement of −1.70 to +1.56 mmHg; the paired t-test showed no significant systematic difference ($p=0.25$). Correlation was strong ($r=0.957$, $p<0.001$) and agreement was excellent (ICC ≈ 0.96). All paired differences (100%) lay within ±2 mmHg. A non-significant trend toward proportional bias was observed ($r=-0.134$, $p=0.058$): NCT read 0.57 mmHg lower at GAT >21 mmHg and 0.29 mmHg higher at GAT <15 mmHg. Conclusion: NCT and GAT demonstrated excellent agreement across the studied IOP range, supporting NCT as a reliable, non-contact screening alternative to GAT in adults. GAT should remain the reference standard for confirmation, particularly at elevated IOP, where NCT showed a slight tendency to under-read.

Keywords: intraocular pressure; non-contact tonometry; Goldmann applanation tonometry; Bland–Altman analysis; method comparison; glaucoma screening; South India

Introduction

Intraocular pressure (IOP) is the single most important modifiable risk factor for the development and progression of glaucoma, the leading cause of irreversible blindness worldwide. Reliable quantification of IOP underpins screening for ocular hypertension, the diagnosis of glaucoma, and the longitudinal monitoring of treatment response. Because therapeutic decisions, including the initiation and escalation of

pressure-lowering therapy, are anchored to measured IOP, even modest differences between measurement techniques can have clinical consequences. The accuracy and reproducibility of tonometry are therefore of considerable practical importance to the practising ophthalmologist.

Goldmann applanation tonometry (GAT) has been regarded as the clinical reference standard for IOP measurement for several decades and remains the technique against which newer instruments are compared [1]. Mounted on the slit lamp, GAT applies the Imbert–Fick principle to a flattened corneal area of fixed diameter and is valued for its accuracy, reproducibility and inter-observer consistency [1,3]. Nonetheless, GAT has well-recognised limitations. It requires direct corneal contact, instillation of topical anaesthetic and fluorescein, and a co-operative seated patient at the slit lamp [1,6]. Repeated applanation can be associated with minor corneal disturbance, and the contact nature of the prism introduces a theoretical risk of microbial cross-contamination unless rigorous disinfection or disposable tips are used [6,8]. GAT readings are further influenced by central corneal thickness (CCT), corneal curvature and the experience of the operator, with thicker corneas tending to yield overestimates and thinner corneas underestimates of true IOP [5,12]. These constraints limit the suitability of GAT for high-volume screening, for children, and for patients who cannot be positioned at the slit lamp.

Non-contact (air-puff) tonometry (NCT) was developed to address several of these limitations. NCT estimates IOP from the time taken by a calibrated jet of air to flatten a defined corneal area, without instrument-to-cornea contact, topical anaesthesia, or fluorescein [2,3]. The absence of corneal contact essentially eliminates the risk of epithelial trauma and cross-infection, makes the technique well suited to mass screening, and allows measurement by trained non-physician personnel [14]. Modern NCT devices are rapid, largely automated and operator-independent, attributes that are particularly attractive in resource-constrained, high-throughput settings such as outreach camps and busy outpatient departments. These same advantages have prompted extensive evaluation of whether NCT can substitute for GAT without unacceptable loss of accuracy [3,4,9].

A substantial body of method-comparison research has examined the relationship between NCT and GAT across diverse populations and clinical contexts, including normal subjects, treated glaucoma patients, post-keratoplasty eyes and gas-filled vitrectomised eyes [3,4,8,10]. The reported findings are broadly favourable but not uniform; some studies describe close agreement, whereas others report systematic over- or under-estimation that varies with the IOP range and with CCT [5,9,12]. Such heterogeneity reflects genuine differences in instruments, populations and corneal biomechanics, and underscores that agreement established in one setting cannot be assumed to hold in another. Method-comparison studies that quantify both systematic bias and the limits of agreement, rather than correlation alone, are therefore essential before a screening instrument is adopted into routine practice.

Despite the global volume of evidence, agreement data derived specifically from South Indian populations remain limited, even though the regional burden of glaucoma and the demand for efficient, infection-conscious screening are both high. Population-specific corneal characteristics and the practical realities of high-volume clinics in this region justify locally generated evidence. The present hospital-based cross-sectional study was therefore undertaken to compare IOP measured by NCT and GAT in adult patients attending a tertiary care teaching hospital in South India, and to characterise their agreement using Bland–Altman analysis and the intraclass correlation coefficient.

Materials and Methods

Study design and setting

This was a hospital-based, cross-sectional, method-comparison study conducted in the Department of Ophthalmology at Tertiary Care Teaching Hospital, India, over the study period six months. The study evaluated the agreement between two methods of IOP measurement, NCT and GAT, performed in the same patient during a single clinic visit.

Study population

Consecutive adult patients (aged 18 years or older) attending the ophthalmology outpatient department who consented to participate were eligible for inclusion. Patients were excluded if they had corneal pathology, scarring or irregularity precluding reliable applanation; a history of corneal or intraocular surgery; active ocular surface or external infection; nystagmus or inability to maintain fixation; or any condition that prevented co-operative positioning at the slit lamp. Eyes with conditions known to confound applanation tonometry were not measured.

Sample size

A total of 200 adults were enrolled. This sample size is consistent with that of comparable published method-comparison studies of tonometry and provides adequately narrow confidence intervals around the mean difference and the Bland–Altman limits of agreement for the precise estimation of inter-method agreement [1,2].

Measurement protocol

For each participant, IOP was measured by both methods in the same sitting. NCT was performed first to avoid any influence of corneal contact, topical anaesthetic or fluorescein on the subsequent non-contact reading; the air-puff measurement was obtained according to the manufacturer's standard operating procedure, with the device-generated average used for each eye. After an appropriate interval, GAT was performed at the slit lamp following instillation of topical anaesthetic and fluorescein, with the examiner masked to the NCT result and reading the dial to the nearest whole millimetre of mercury. Both eyes of each participant were measured by each method. To account for the correlation between fellow eyes and to provide a single representative value per individual, the per-patient mean of the two eyes was computed for each method and used in all analyses.

Statistical analysis

Data were summarised using means and standard deviations for continuous variables and frequencies with percentages for categorical variables. Agreement between NCT and GAT was assessed using a complementary set of methods. The paired t-test was used to test for a systematic difference between the two techniques. The strength of linear association was quantified by the Pearson correlation coefficient, and overall agreement by the two-way intraclass correlation coefficient (ICC). Agreement was further characterised by the Bland–Altman method: the mean of the paired differences (NCT − GAT) provided the estimate of systematic bias, and the 95% limits of agreement were calculated as the mean difference ± 1.96 standard deviations of the differences. The proportion of paired differences falling within ±2 mmHg was determined as a clinically relevant agreement criterion, and the relationship between the paired difference and the mean of the two measurements was examined to assess for proportional bias. A two-sided p value of less than 0.05 was considered statistically significant.

Results

Participant characteristics

A total of 200 adults were included in the analysis. The mean age was 52.6 (SD 18.2) years. Men constituted 109 (54.5%) of the cohort and women 91 (45.5%). The baseline characteristics of the participants are summarised in Table 1.

Table 1: Baseline characteristics of participants (N = 200)

Characteristic	Value
Number of participants	200
Mean age, years (SD)	52.6 (18.2)
Male, n (%)	109 (54.5)
Female, n (%)	91 (45.5)

Intraocular pressure by method and systematic difference

The mean IOP was 17.47 (SD 2.78) mmHg by NCT and 17.54 (SD 2.89) mmHg by GAT. The mean difference (NCT − GAT) was −0.07 mmHg (SD 0.83), indicating that NCT read, on average, only marginally lower than GAT. The paired t-test demonstrated no statistically significant systematic difference between the two methods (p=0.25). The 95% limits of agreement extended from −1.70 to +1.56 mmHg. These results are presented in Table 2.

Table 2. Mean intraocular pressure by method and mean difference with limits of agreement

Parameter	Value
Mean NCT IOP, mmHg (SD)	17.47 (2.78)
Mean GAT IOP, mmHg (SD)	17.54 (2.89)
Mean difference (NCT − GAT), mmHg (SD)	−0.07 (0.83)
95% lower limit of agreement, mmHg	−1.70
95% upper limit of agreement, mmHg	+1.56
Paired t-test, p value	0.25

Bland–Altman analysis

The Bland–Altman plot of the paired differences against the mean of the two measurements is shown in Figure 1. The mean-difference line lay close to zero (−0.07 mmHg) and the limits of agreement (−1.70 to +1.56 mmHg) were narrow, with the differences distributed evenly above and below the bias line across the observed range of IOP. Notably, all paired differences (100%) fell within ±2 mmHg, confirming clinically acceptable agreement throughout the studied range.

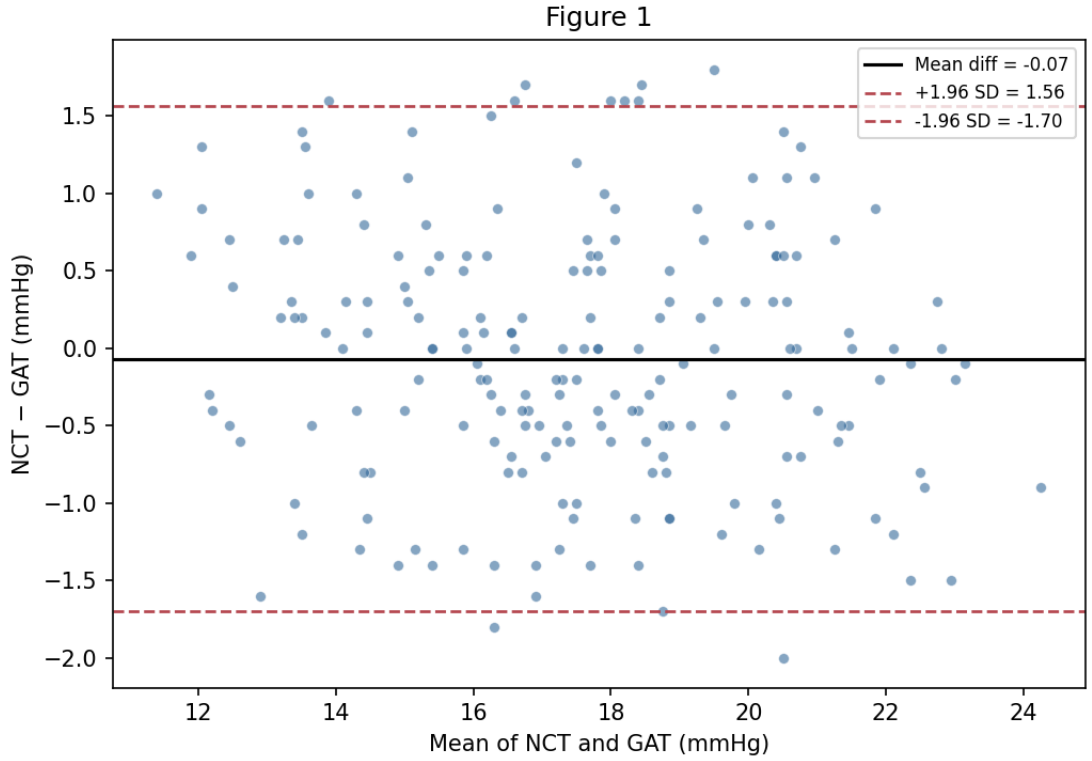

Figure 1: Bland–Altman plot of the agreement between non-contact tonometry (NCT) and Goldmann applanation tonometry (GAT). The x-axis shows the mean of the two measurements per patient and the y-axis the difference (NCT − GAT). The solid line indicates the mean difference (−0.07 mmHg) and the dashed lines the 95% limits of agreement (−1.70 and +1.56 mmHg).

Correlation and agreement metrics

There was a strong, statistically significant linear association between the two methods (Pearson r=0.957, p<0.001), and overall agreement was excellent (ICC ≈ 0.96). The scatter plot of GAT against NCT with the line of identity is shown in Figure 2; the points clustered closely along the line of identity, consistent with the high correlation and minimal systematic bias.

Figure 2

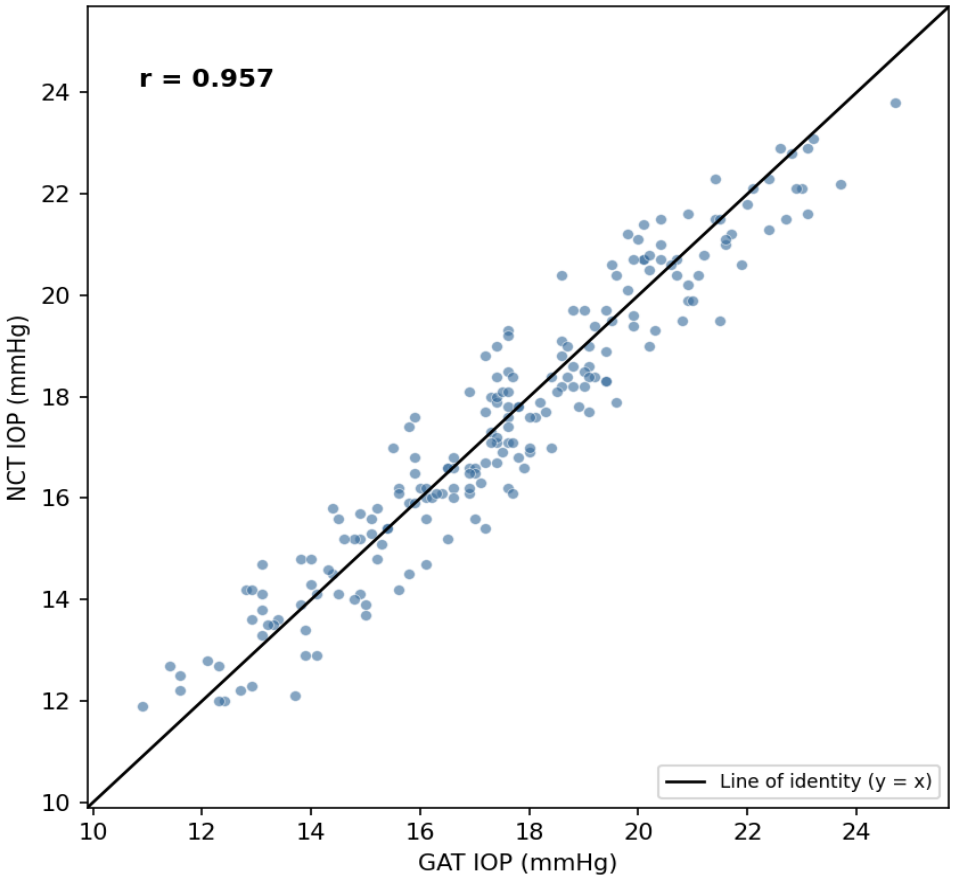

Figure 2. Scatter plot of Goldmann applanation tonometry (GAT) against non-contact tonometry (NCT) intraocular pressure, with the line of identity (y = x). The Pearson correlation coefficient was r=0.957.

A minor, non-significant trend toward proportional bias was observed: the difference (NCT − GAT) correlated weakly and negatively with the mean of the two measurements (r=−0.134, p=0.058). Examination by IOP range showed that at higher GAT values (>21 mmHg), NCT read on average 0.57 mmHg lower than GAT, whereas at lower GAT values (<15 mmHg), NCT read on average 0.29 mmHg higher. The agreement metrics and the difference by IOP range are summarised in Table 3.

Table 3: Agreement metrics and mean difference by intraocular pressure range

Metric	Value
Pearson correlation coefficient (r)	0.957 (p<0.001)
Intraclass correlation coefficient (ICC)	≈ 0.96
Paired differences within ±2 mmHg	100%
Difference vs mean (proportional bias), r	−0.134 (p=0.058)
Mean difference at GAT >21 mmHg (NCT − GAT), mmHg	−0.57
Mean difference at GAT <15 mmHg (NCT − GAT), mmHg	+0.29

Discussion

In this hospital-based cross-sectional study of 200 adults attending a tertiary care teaching hospital in South India, IOP measured by NCT and GAT showed excellent agreement. The mean difference was negligible (−0.07 mmHg) and statistically non-significant (p=0.25), the limits of agreement were narrow (−1.70 to +1.56 mmHg, a span of approximately ±1.6 mmHg), correlation was strong (r=0.957) and overall agreement was excellent (ICC ≈ 0.96). Critically, all paired differences lay within ±2 mmHg, a margin generally regarded as clinically acceptable for routine IOP assessment. Taken together, these findings indicate that, in an unselected adult outpatient population spanning the clinically common IOP range, NCT provides measurements that are interchangeable with GAT for screening purposes.

These results are concordant with the broader method-comparison literature. Tonnu and colleagues, in a detailed comparison of four tonometry methods, reported good agreement and emphasised that the assessment of any tonometer must consider both systematic bias and the limits of agreement rather than correlation alone [1]. The strong correlation observed here (r=0.957) echoes the high correlations reported across multiple studies of air-puff and contact tonometry [3,9], but, in keeping with established method-comparison principles, our central conclusion rests on the near-zero bias and narrow limits of agreement rather than on correlation, which measures association rather than agreement [1]. Yilmaz et al. similarly found acceptable agreement between GAT, non-contact air-puff tonometry and the Tono-Pen in normal subjects [3], and Jorge et al. reported comparable agreement between the Reichert R7 non-contact tonometer and GAT [9]. The present data extend these observations to a South Indian outpatient population, addressing a regional evidence gap.

Particularly relevant is the work of Mohan et al., who compared a non-contact tonometer with GAT in an Indian population and likewise found close agreement, supporting the applicability of NCT in this setting [2]. Our findings reinforce theirs and add Bland–Altman-based limits of agreement and ICC from a separate South Indian cohort. The observed pattern, in which agreement is excellent overall but accompanied by a slight, non-significant tendency for NCT to under-read at higher IOP, is also consistent with reports in treated glaucoma patients, where the behaviour of non-contact and rebound tonometers relative to GAT has been shown to vary modestly across the IOP range [4]. Studies in specialised contexts, such as post-penetrating-keratoplasty eyes [8] and gas-filled vitrectomised eyes [10], further illustrate that the agreement between NCT and GAT is sensitive to corneal and ocular conditions, reinforcing that favourable agreement in normal corneas should not be extrapolated uncritically to abnormal eyes.

A consistent theme in the literature is the influence of central corneal thickness on tonometric readings. Babalola et al. demonstrated that CCT materially affects both GAT and non-contact tonometer measurements in indigenous African eyes [5], and Carbonaro et al., comparing three methods of IOP measurement, found that their relationship was modulated by CCT [12]. Other comparative work involving dynamic contour tonometry, the Icare and the Corvis ST has similarly highlighted that corneal biomechanical properties, not merely true IOP, contribute to inter-method differences [11,13]. The small proportional trend we observed, with NCT reading marginally lower at higher GAT values and marginally higher at lower values (r=−0.134, p=0.058), is compatible with a subtle biomechanical or regression-to-the-mean effect and did not reach statistical significance; nonetheless, it accords with the general observation that air-puff devices may slightly under-read in the higher pressure range. Because CCT was not adjusted for in the present analysis, residual corneal influence on individual readings cannot be excluded.

The clinical implications of these findings are substantial. The principal advantages of NCT, namely the absence of corneal contact, topical anaesthesia and fluorescein, translate directly into improved infection

control and patient acceptability, and into the feasibility of rapid, operator-independent measurement by trained non-physician staff [6,14]. In high-throughput settings such as glaucoma screening programmes and outreach camps, where efficiency, hygiene and scalability are paramount, an instrument that agrees closely with GAT yet avoids corneal contact is especially valuable [14]. The repeatability of non-contact devices has also been examined favourably relative to repeated GAT applanation [6,7]. Our data support the use of NCT as a first-line screening tool in adults, with the expectation that the great majority of readings will fall within 2 mmHg of the GAT value.

These advantages must, however, be balanced against an important caveat: GAT remains the clinical reference standard, and the slight tendency of NCT to under-read at higher IOP carries particular weight for the very patients in whom accurate measurement matters most, namely those with elevated pressures and suspected or established glaucoma. A reading that is even modestly lower than the true value at high IOP could, in principle, delay recognition of inadequately controlled disease. Accordingly, while NCT is well suited to screening and to monitoring within the normal range, abnormal or borderline-high NCT readings should be confirmed by GAT, and clinically important management decisions should continue to be informed by the reference technique, especially at elevated IOP [1,4].

Conclusion

In adult patients attending a tertiary care teaching hospital in South India, non-contact tonometry and Goldmann applanation tonometry demonstrated excellent agreement, with a near-zero mean bias, narrow limits of agreement of approximately ±1.6 mmHg, an intraclass correlation coefficient of about 0.96, and all paired differences within ±2 mmHg. NCT is therefore a reliable, non-contact alternative to GAT for IOP screening in adults, offering clear advantages in infection control, ease of use and suitability for high-volume measurement. Given the slight, non-significant tendency of NCT to under-read at higher IOP, GAT should remain the reference standard for confirmation and for clinically important management decisions, particularly in patients with elevated intraocular pressure.

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