ORIGINAL ARTICLE

Comparing Dynamic Contour Tonometry to Goldmann and Hand-Held Tonometry in Normal, Ocular Hypertension, and Glaucoma Populations

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ABSTRACT

We prospectively compared dynamic contour tonometry (DCT) to Goldmann (GAT) and hand-held tonometry (HHT) in normal, ocular hypertension, and glaucoma populations. Both measurements were made on each patient within a 5-minute period during routine office exams over 4 months.

While DCT is in good overall agreement with GAT and HHT, there is some systematic deviation at different pressure ranges in normal, ocular hypertension, and glaucoma populations.

INTRODUCTION

Measurement of intraocular pressure (IOP) is one of the basic diagnostic tools in glaucoma diagnosis. In prior studies *(1–4)*, dynamic contour tonometry (DCT) has been well correlated with Goldmann applanation tonometry (GAT). However, large clinical settings often employ hand-held tonometry (HHT). Because of the prevalent HHT usage, we investigated whether there is a significant difference in HHT vs GAT vs DCT measurements in a larger office population. Tonometric readings were taken in general population, ocular hypertension (OHT), and patients with glaucoma in the same sitting.

Factors related to contact tonometry may be altered by corneal thickness, mire thickness, observer variability, and repeat tonometry variability *(5–9)*. DCT, however, did differ slightly from GAT (mean difference of 1.7 and 1.8 mmHg, respectively) in two recent studies, which took corneal thickness into consideration *(1–2)*. DCT, which measures the diastolic pressure, would not be affected by mire thickness, but still required transducer contour to tear meniscus to initiate measurement. To date, there have been no studies comparing normal, OHT, and glaucoma populations using HHT, GAT, and DCT. To quantitatively assess how much contact tonometry measurements vary from contour tonometry in normal, OHT, and glaucoma populations, we

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DISCLOSURE
The authors have stated that they do not have a significant financial interest or other relationship with any product manufacturer or provider of services discussed in this article. The authors also do not discuss the use of off-label products, which includes unlabeled, unapproved, or investigative products or devices.

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prospectively measured both eyes of each patient using HHT, GAT, and DCT in the same sitting in 267 ophthalmic office patients over a 4-month interval.

MATERIALS AND METHODS

After obtaining informed consent from each patient, a cohort of 79/267 patients with OHT, 42/267 patients with open-angle glaucoma, and 146/267 patients from a general ophthalmic urban population, underwent ophthalmic exam (medical history, visual acuity, refraction, keratometry, motility, biomicroscopy, direct and indirect ophthalmoscopy, and when necessary, visual fields). No patients in the cohort had undergone refractive surgery, had ocular surgery within the last 6 months, had corneal edema or scars, or active uveitis.

Patients were considered to have OHT if they had three or more prior visits with ocular pressures above 21 mmHg, cup:disc ratios of 0.3–0.5 without any signs of central cup pallor, thinning of the optic nerve rim, disc hemorrhage, nerve fiber layer defects or peripapillary atrophy, and normal Humphrey 30–2 visual fields on two occasions or more.

Patients were considered to have glaucoma if they had three or more visits with ocular pressures above 21 mmHg, cup:disc ratios above 0.5 with signs of glaucomatous optic nerve damage, (increased number of bare lamina cribrosa, vessel down sloping, central pallor or disc rim reduction, or disc hemorrhage), and three or more Humphrey 30–2 visual fields with arcuate scotoma or encroaching on central visual field loss.

Patients were considered in the general ophthalmic population if they had no history of OHT, glaucoma, uveitis, retinal vascular lesions, ocular infections, corneal disease, recent ocular surgery, or cervical, thoracic, or sacral limitations precluding chair measurements of IOP. These general ophthalmic population patients were usually coming for refraction update needs.

All measurements were taken by the same examiner in the following order: HHT, GAT, and DCT. The examiner had practiced DCT on several co-workers not included in the study until quality 1 and 2 tracings were readily obtained on DCT printouts. In cases where HHT or GAT outcomes were in doubt because of mires, tear level, or dye distribution, borderline elevated astigmatism (>2.5 diopters), or strabismus with vertical or horizontal deviation, another drop of tetracaine 0.5% and floroscein strip were re-applied and the measurement was repeated. If the repeat reading was clear it was utilized in the data. If it was still unclear as to the end point, then the patient was excluded from the study.

HHT measurements were performed using the Kowa HA-2 hand held applanation tonometer (Kowa, Japan), calibrated previously according to the manufacturer's guidelines. For GAT, a slit lamp (Carl Zeiss, Germany) with a Goldmann tonometer was used, calibrated according to the manufacturer's guidelines. Dynamic contour tonography was performed using a slit lamp mounted Pascal Dynamic Contour Tonometer (Swiss Microtechnology AG, Port Switzerland) self calibrating; DCT-Pascal is a new method of IOP measurement using contour matching of the cornea *(10)*, digital tracings from the liquid crystal display of the diastolic impulse amplitude were made on each patient. The quality of the DCT data, scaled from 1 to 5, is recorded on a digital display along with a digital pressure measurement. Only data with quality 1–3 tracings were used; all quality 3 readings were repeated; an average was taken of two quality 3 tracing patients if they were different. DCT recording time was at least 10 seconds.

During the course of the exam each patient underwent HHT, GAT, and DCT, in sequence within 3 to 5 minutes, after one to two drops of 0.5% tetracaine. DCT was always performed subsequent to HHT and GAT, reducing measurement bias of the electronic data presentation on the HHT and GAT.

Because the focus of this study was to compare HHT, GAT, and DCT—and as was mentioned above, two prior studies *(1,2)* and a more recent study *(11)* showed no correlation between DCT and corneal thickness—pachymetry was not included in this study.

Statistical Analysis

Statistical analysis was performed using SPSS (Statistical Software, Chicago, IL) and Microsoft Excel (Washington, USA). In the 267-patient population (Fig. 1), the Kolmogorov-Smirnov test demonstrated a normal distribution for HHT ($p < 0.001$) and GAT ($p < 0.001$), but was not normal for the DCT measurements ($p < 0.22$). Therefore, in this study, comparisons of standard deviations and associated normally distributed confidence intervals among the glaucoma, OHT, and general ophthalmic population subgroups cannot be applied in DCT comparisons. Our alternate statistical methodology to deal with the non-normal DCT distribution (in comparing DCT with HHT and GAT, respectively) was to randomly partition our patient population ($n = 267$) into five subgroups. Each subgroup (that compared DCT with HHT and GAT, respectively) was regressed against the 45° line (line of random difference; *see* Fig. 2). The slope

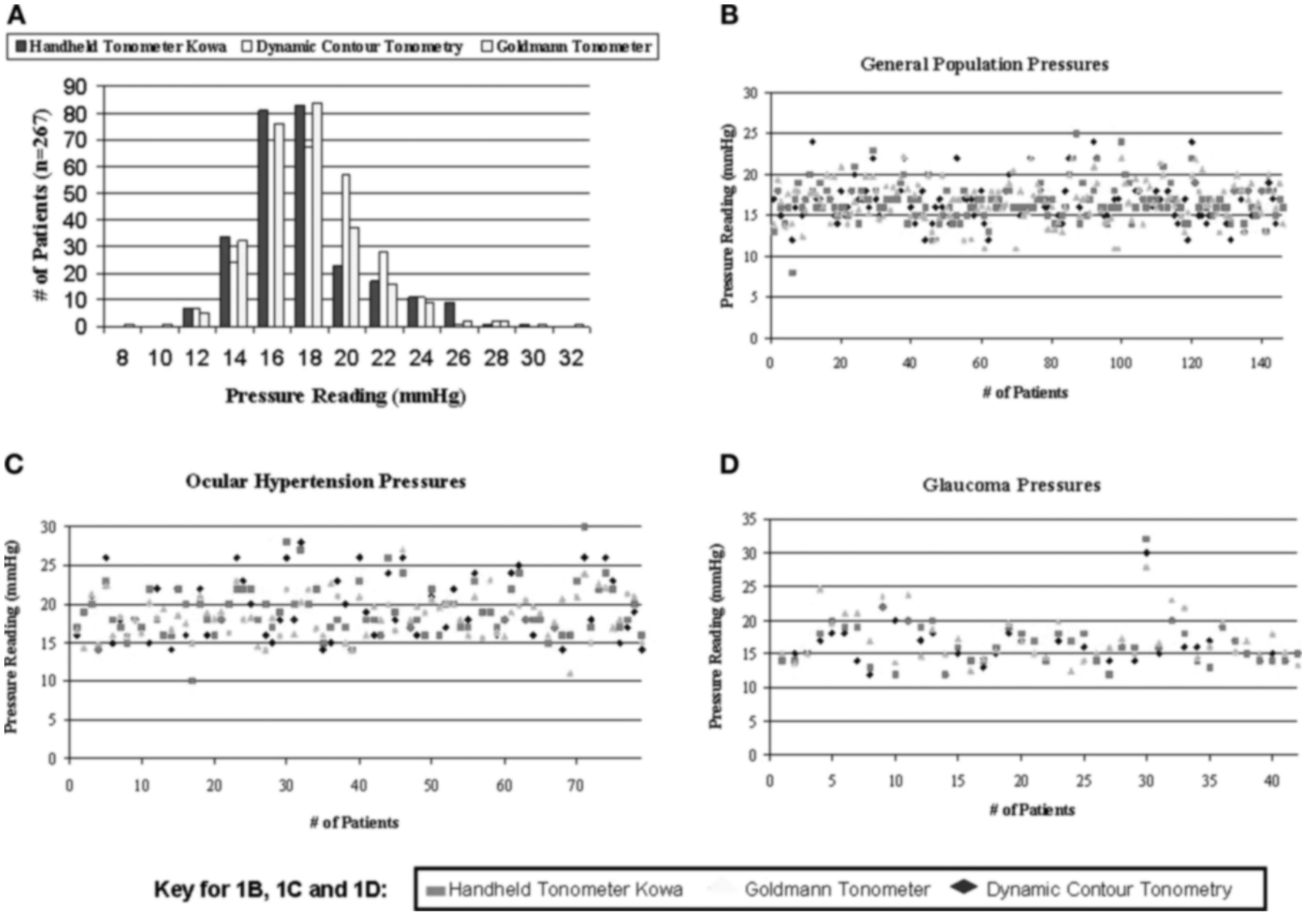

Figure 1—Distributions of pressures in **(A)** entire population studied (n = 267); **(B)** general population (n = 146); **(C)** ocular hypertension (n = 79); **(D)** glaucoma population (n = 42).

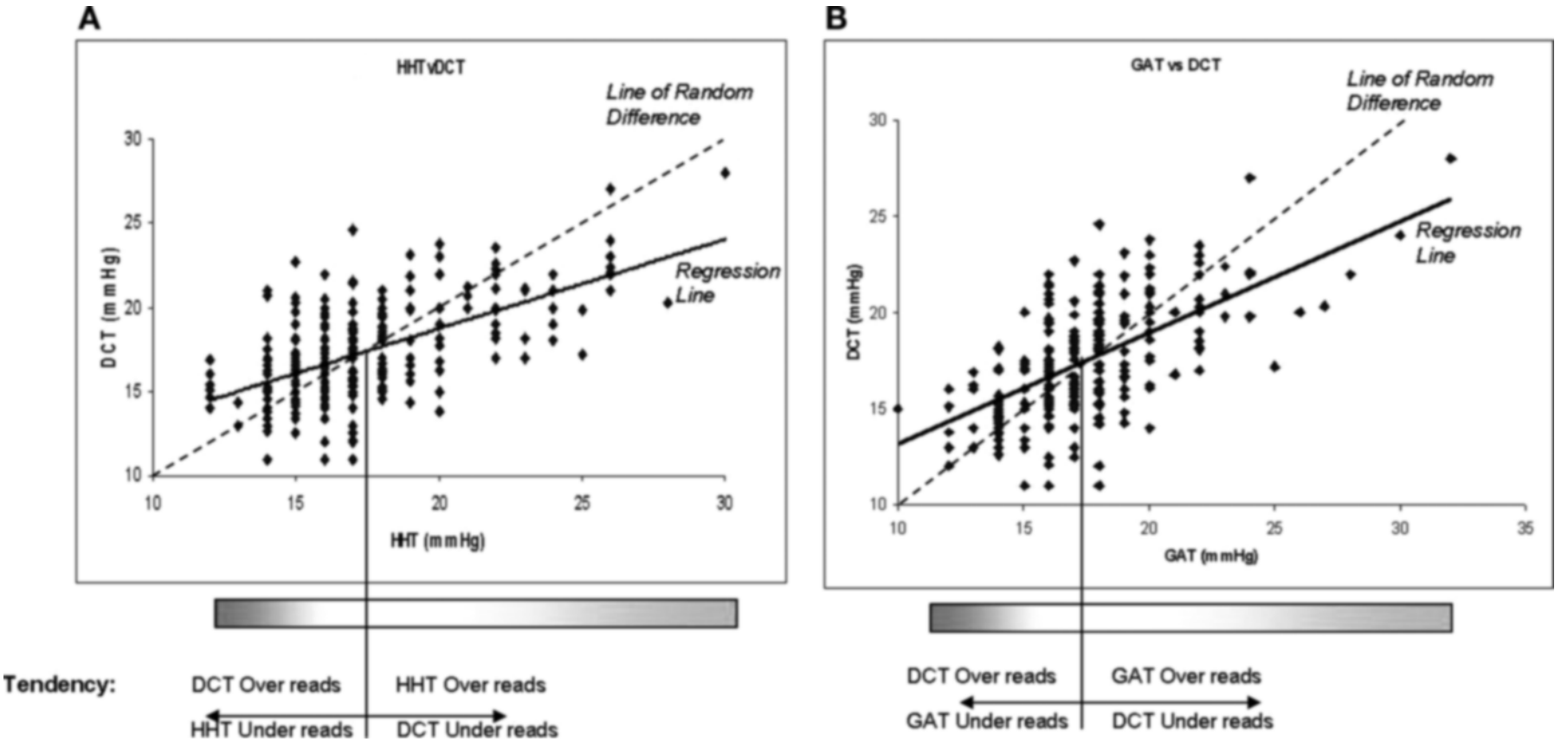

Figure 2—Tonometry measurements for global patient population (n = 267): **(A)** HHT vs DCT and **(B)** GAT vs DCT. DCT has an increasing tendency to over read relative to HHT and GAT at lower pressures (i.e., prior to the crossing of the regression line and the line of random difference) and under read at higher pressures (i.e., after the regression line and the line of random difference cross).

of all five subgroup regressions was less than the 45° line. Thus, there is a greater than 96.8% probability ($P = 1-(1/2)^5 > 96.8\%$) that this did not occur randomly.

Pearson correlation coefficients and Bland-Altman analyses *(12)* were computed. To represent the amount of disagreement between two different measurement techniques, which are not apparent from r-value coefficient, Bland-Altman plots were generated for both HHT vs DCT and GAT vs DCT. The difference in pressure of every pair of measurements was plotted as a function of their mean. This represents the closest approximation to the real IOP *(12)*.

In the global population distribution comparing HHT, GAT, and DCT in the 267-patient group, just the right eye of each patient was randomly selected and tallied in all statistical computations. To identify the mean difference between HHT and DCT, GAT and DCT, and HHT and GAT in OHT/glaucoma, and general population groups, Bland-Altman plots were used to quantitatively assess the amount of disagreement between two groups.

RESULTS

Patients with OHT, glaucoma, refractive errors of a New York City ophthalmic practice ($n = 267$) were measured were measured with hand-held, Goldmann, and Pascal tonometry. The range of pressures is shown in the histogram in Fig. 1A. Fig. 1B–D illustrates the distribution of HHT, GAT, and DCT pressures obtained in the general population, OHT, and glaucoma population.

Measurements showed a close correlation between both HHT and DCT, and GAT and DCT IOP readings (Fig. 2A,B). Mean IOP readings were comparable for DCT relative to HHT and GAT. Mean HHT and GAT were 17.4 mmHg and mean DCT was 17.3 mmHg.

Because the Kolmogorov–Smirnov test was normal for the distribution of the HHT (standard deviation = 3.2) and GAT (standard deviation = 3.1) measurements, but was not normal for DCT (mean = 17.3), standard deviations are not presented for DCT. The differences between the measurements on individual patient tonometric pressures were analyzed according to Bland-Altman plots. The Bland-Altman plots, shown in Figs. 3 and 4, illustrated a mean difference between DCT and HHT of 0.1 mmHg in the general population (Fig. 3A,B, $n = 146$) and a 0.06-mmHg difference in the glaucoma/OHT population (Fig. 4A,B, $n = 121$). The mean difference between GAT and DCT was 0.07 mmHg in the general population (Fig. 4A) and 0.13 in the glaucoma/OHT population (Fig. 4B).

The mean of these deviations turned out to be close to 0, indicating that in the overall population no bias was found in either of the techniques compared. However, a comparison of the regression lines from the three measurements—HHT vs DCT and GAT vs DCT (Figs. 2A,B)—with the 45° line (the line that would result in totally randomized differences between the two techniques compared) indicated a clinically significant difference. Specifically, the regression line in each comparative plot (Fig. 2A,B) shows that DCT tends to be slightly higher than both HHT and GAT for readings less than 18 mmHg. However, for readings above 18 mmHg, DCT tends to be slight lower than both HHT and GAT. As discussed in "Methods" section, the deviation of the regression lines from the 45° line is statistically significant. Also, the underestimates and overestimates indicated by the regression lines resulted in the near cancellation of the bias when the complete range of pressures was considered.

The Pearson correlation coefficient for HHT and DCT in the global population was r = 0.59. (Treatment of the DCT distribution is discussed in "Methods" section.) Similarly, the Pearson correlation coefficient in the global population for GAT and DCT had an r = 0.63. Despite the diverse general patient population, only five patients were excluded from the study. Three had exotropia, which resulted in poor fixation and two had more than 3.0 diopters of astigmatism. The poor fixation precluded high quality DCT readings and the high astigmatism resulted in uncertainty of mires for HHT and GAT, but quality DCT.

In comparing HHT to GAT (Fig. 5), the mean difference between measurements was close to zero and the 95% confidence interval of the difference between measurements was approx 2.5 mmHg in the general population and slightly higher than 3.0 in the OHT/glaucoma population.

DISCUSSION

In this study involving OHT/glaucoma, and general population groups there was excellent overall agreement between HHT, GAT, and DCT. Unlike other studies *(1,2)*, which did not include glaucoma, OHT, and general ophthalmic patients, this study showed correlation of HHT, GAT, and DCT measurements in three patient populations. Also, this study showed correlation between HHT, GAT, and DCT, whereas the prior studies just compared GAT and DCT. Since HHT is a very commonly used measurement device in glaucoma screening settings, the comparison of HHT to GAT and DCT is currently quite clinically relevant. HHT and GAT (Fig. 5) were usually within 3 mmHg of each other in the general population and the OHT/glaucoma population.

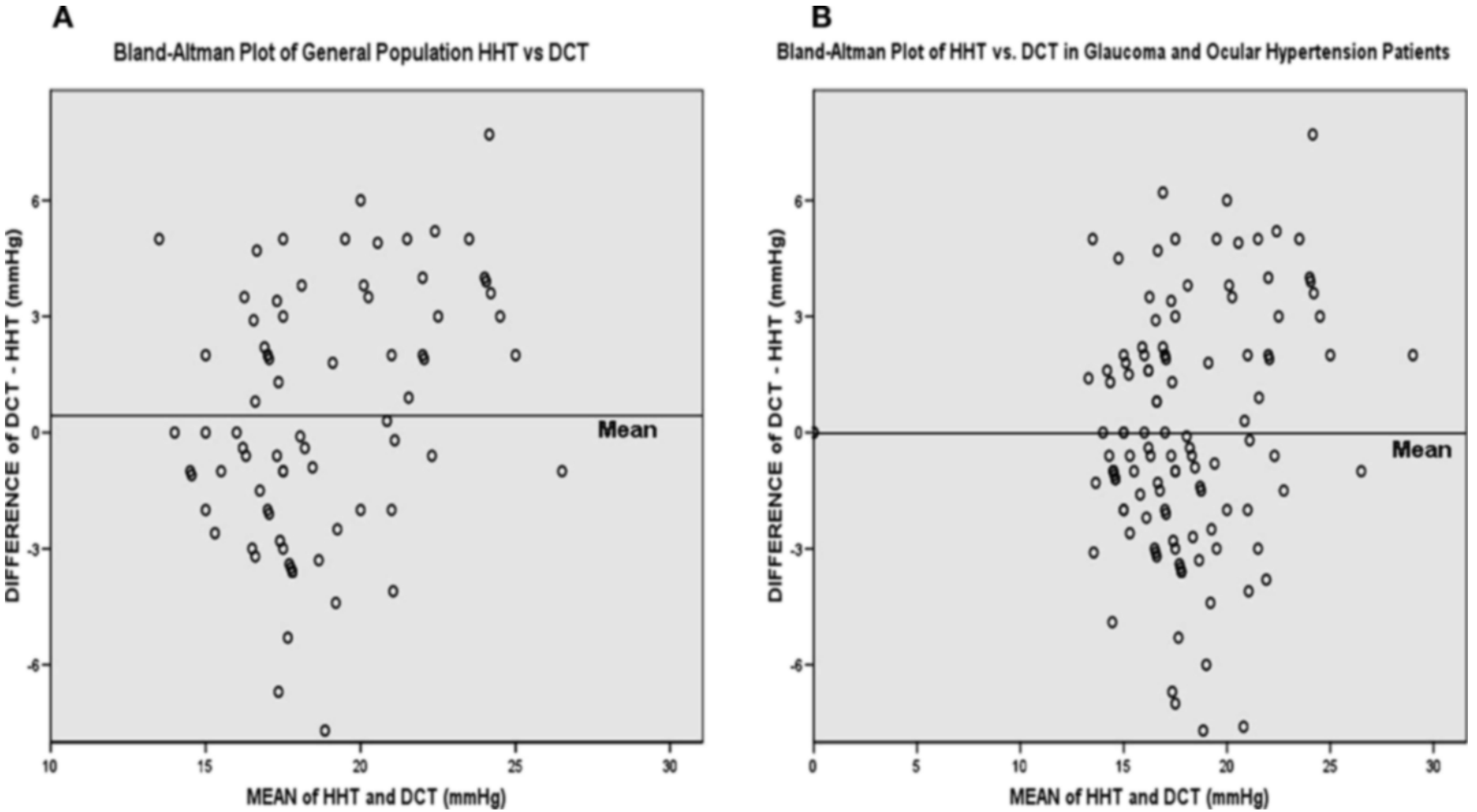

Figure 3—Bland-Altman Plots Showing mean differences in **(A)** general population (n = 146) and **(B)** glaucoma/ocular hypertension population (n = 121) for measurements of HHT vs DCT.

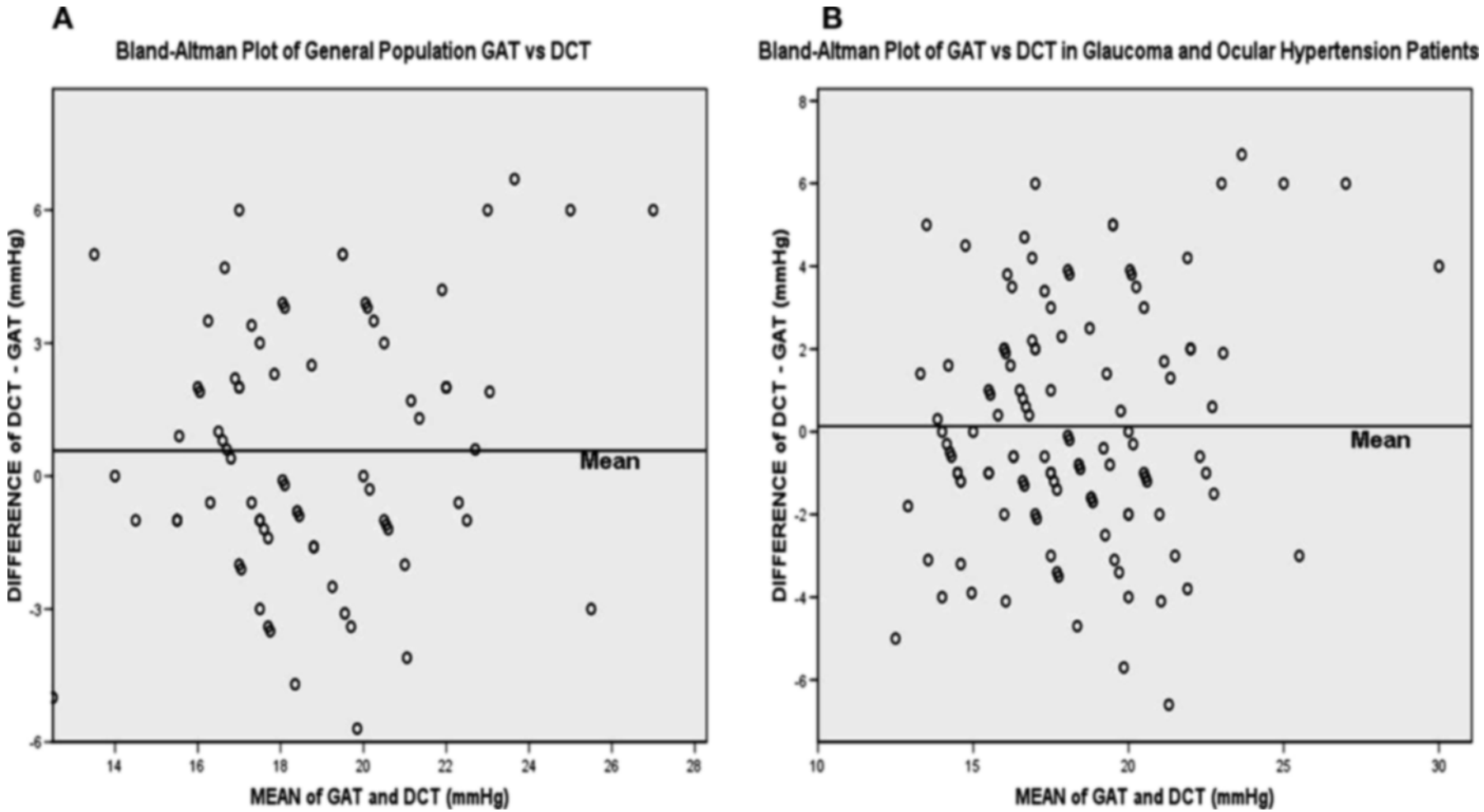

Figure 4—Bland-Altman Plots Showing mean differences in **(A)** general population (n = 146) and **(B)** glaucoma/ocular hypertension population (n = 121) for measurements of GAT vs DCT.

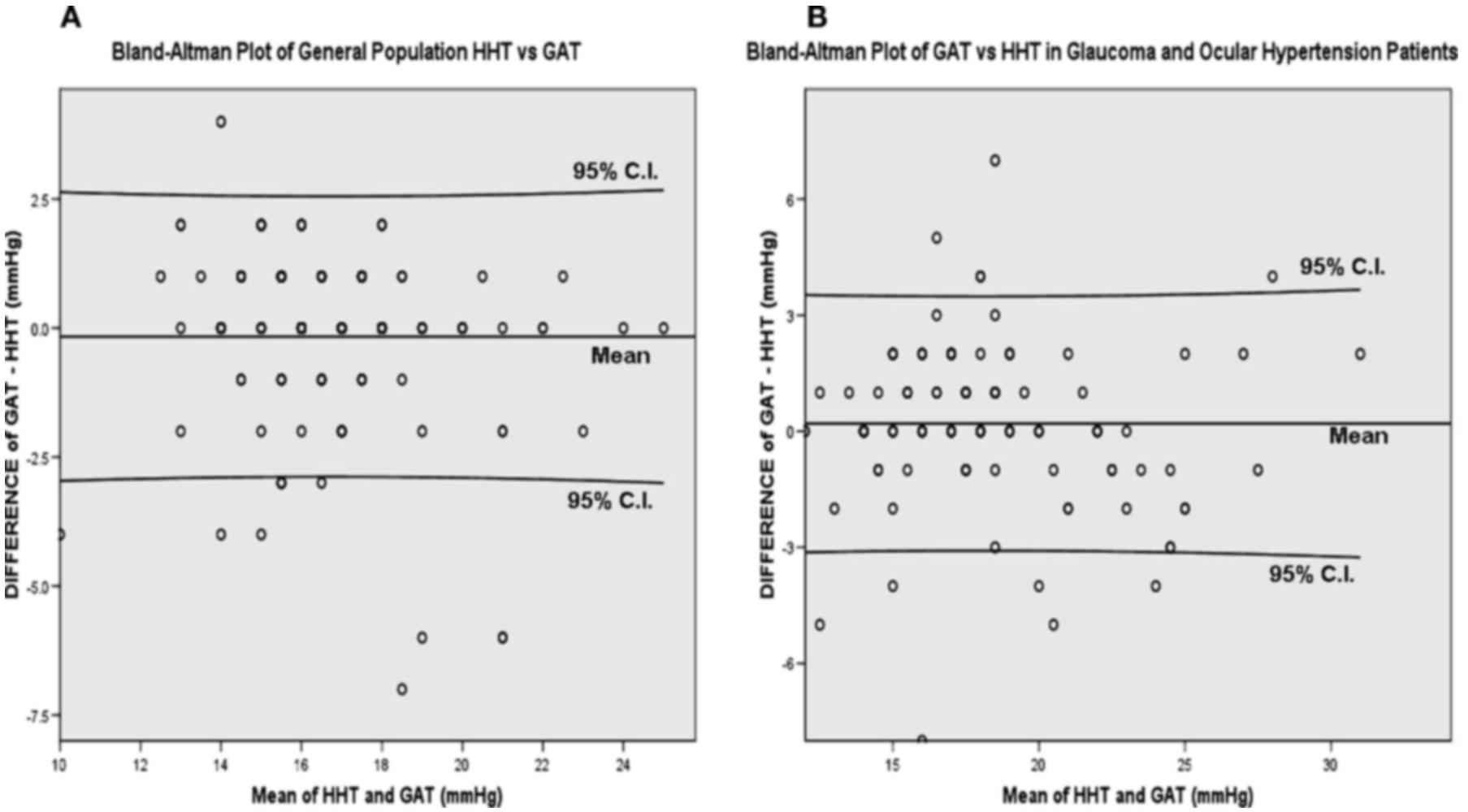

Figure 5—Bland-Altman plots showing mean differences in **(A)** general population (n = 146) and **(B)** glaucoma/ocular hypertension population (n = 121) for measurements of HHT vs GAT.

In reviewing the data of the general population and the OHT/glaucoma population, we concur with the prior observation *(1,2)* that DCT tends to slightly over-read relative to HHT and GAT. However, this overreading tendency may be limited to a certain pressure range. The slopes of the regression lines in Fig. 2A,B were consistently below the 45° line (slope = 1), which would reflect completely random differences between two techniques. Therefore, we indicate in Fig. 2A,B the areas of under-reading and over-reading of DCT relative to HHT and GAT above and below 18, respectively.

This population consists of 121 glaucoma/OHT patients. This probably produced a cohort of slightly higher-pressure readings. Pressure readings above 18 mmHg for HHT and GAT, respectively, reflect tendency to under read the DCT relative to HHT and GAT. From the statistical standpoint, the question is if the deviation between the random line and the regression line slope is systematic or not. To answer this question, we randomly partitioned the patients into five subgroups, each from the general population and the glaucoma/OHT populations and calculated the regression for each subgroup. Each subgroup yielded a regression slope of less than 1.0 (to be specific, 0.42, 0.42, 0.39, 0.55, and 0.83 for HHT vs. DCT; and 0.49, 0.43, 0.48, 0.79, and 0.70 for GAT vs DCT). The probability of this occurring randomly is $(1/2)^5=1/32 = 0.0313$. Thus, we can conclude with 96.8% confidence that at higher pressures the DCT vs HHT/GAT has a slight tendency to under read. This study, similar to Barleon et al. *(11)*, found that DCT IOP is higher than GAT (and HHT) in lower IOPs, but lower than GAT (and HHT) in higher IOPs.

Although DCT was carried out after HHT and GAT, thereby reducing the role of electronic measurement bias on HHT and GAT, it is possible that HHT prior to GAT could have some element of bias in GAT measurement in this single-examiner study. However, instrument calibration of the Kowa hand held tonometer and the Goldmann tonometer was in accord with manufacturer's guidelines. Where keratometry, ectasia, strabismus, nystagmus or physical limitations such as extreme obesity or cervical arthropathy were significant mitigating elements to HHT or GAT, 10 patients were excluded from the study.

Because all of the patients included in this study were not new to the practice, there was no difficulty with acceptance of HHT, GAT, as well as the introduction of DCT. In fact, following a quality 3 DCT tracing, which would prompt the examiner to request another DCT measurement, patients would readily comply with repeat DCT measurement.

In the clinical setting, with normal, OHT, and patients with glaucoma, the quality and quantity of the DCT reading was a reliable measurement of IOP compared to hand held and Goldmann tonometric measurements.

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