Variability of Force Magnitude and Force Duration in Manual and Instrument-Based Manipulation Techniques

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Abstract

Objective: The goal of this study was to compare the variation of manipulative forces produced by instruments and a manual technique.

Methods: Four operators (2 experts and 2 novices) used 4 different mechanical instruments to apply force to a uniaxial load cell. A different group of 2 expert and 2 novice operators used a traditional manual technique to apply force to a sensor mat. Two primary outcome variables were obtained from each sensor system: peak-to-peak force magnitude (N) and peak-to-peak force duration (millisecond). Multiple analyses were performed to determine the absolute differences and variation in each variable.

Results: Force-producing instrumentation exhibited less variation in absolute force and force duration compared to manual techniques. However, the same instrument in the hands of different operators often produced significantly different values of absolute force and force duration. Although absolute values of force magnitude generally differed between operators, intraoperator variation was equal for instruments and the manual technique. Conversely, for force duration, significant differences in interoperator variability were observed for the manual technique and for one of the instruments.

Conclusions: Force-producing instruments reduce absolute variation in force magnitude and duration. However, this reduction does not eliminate significant differences in absolute force parameters observed to occur between some operators using the same instrument. Given these observations, claims of instrument superiority that do not account for interoperator variability should be considered with caution. (J Manipulative Physiol Ther 2006;29:611-618)

Key Indexing Terms: *Manipulation, Spinal; Reproducibility of Results; Instrument*

Manipulation is a common therapeutic intervention used by different professions to treat musculoskeletal conditions such as low back pain. While there have been attempts to standardize the application of manipulation through clinical guidelines,[1-3] clinical responses to manipulation are known to vary.[4-8] Although the primary source of this variation is thought to be patient heterogeneity,[9,10] variation in the application of manipulation itself may be an additional factor. Indeed, prior investigations have reported that manipulation can vary significantly in terms of force magnitude,[11,12] force duration,[13] and the location of force application.[14] Although the clinical significance of these sources of variation is not yet understood, their reduction is presumed to be beneficial, as is the case in other physical interventions.[15-20]

One approach to reduce variability in manipulation would be to standardize its application through instrumentation, an approach taken with other therapeutic tasks where human variability may be detrimental.[21-24] To this end, instrumentation to apply manipulative forces now exists and represents the second most common approach for applying manipulative forces.[25] Unfortunately, there is little evidence to suggest these instruments reduce application variability compared to manual methods. Given this background, the goal of this study was to describe the

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Table 1. *Mean values and SDs of forces generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings). Also shown are force data generated by 4 different operators using a manual technique*

	Force (N)			
	Expert 1	Expert 2	Novice 1	Novice 2
Activator IV*	169.771 ± 8.589	177.595 ± 4.933	177.315 ± 4.604	174.334 ± 4.831
Air Activator*	207.331 ± 9.239	188.361 ± 12.045	210.593 ± 12.017	193.724 ± 13.357
Impulse*	174.554 ± 6.851	181.037 ± 6.053	163.508 ± 9.081	182.998 ± 4.978
Signature*	133.111 ± 3.941	133.131 ± 3.404	136.974 ± 3.579	136.934 ± 5.847
	Expert A	Expert B	Novice A	Novice B
Manual	253.654 ± 37.738	157.408 ± 24.624	256.773 ± 49.836	387.432 ± 61.526
	Duration (ms)			
	Expert 1	Expert 2	Novice 1	Novice 2
Activator IV*	1.098 ± 0.08	1.146 ± 0.03	1.266 ± 0.075	1.324 ± 0.086
Air Activator*	0.856 ± 0.032	0.776 ± 0.018	0.86 ± 0.016	0.902 ± 0.011
Impulse*	0.76 ± 0.086	0.656 ± 0.026	0.756 ± 0.016	0.77 ± 0.051
Signature*	0.882 ± 0.049	0.996 ± 0.04	1.112 ± 0.06	1.246 ± 0.037
	Expert A	Expert B	Novice A	Novice B
Manual	66.924 ± 5.152	99.882 ± 13.897	164.228 ± 55.745	250.889 ± 87.429

* $P \leq .05$ (significant difference).

variation in forces delivered by mechanical and manual methods of manipulation.

Methods

Overview

Four operators used 4 different mechanical instruments to apply force to a uniaxial load cell. A different group of 4 operators used a traditional manual technique to apply force to a sensor mat. Outcome variables obtained from each sensor were peak-to-peak force magnitude and peak-to-peak force duration.

Instruments

Clinicians who wish to apply forces by instrument have numerous choices of devices by which to do so. In addition, these instruments use different technologies (spring, compressed gas, and electromechanical) to generate force through a blunt stylus that contacts the skin. Given this selection, we adopted a pragmatic approach and tested a selection of instruments that represented each of these technologies. Although several spring-based instruments exist, the Activator IV (Activator Methods International, Phoenix, Ariz) is arguably the most popular of these instruments. This instrument has 4 discrete force settings that act by limiting spring displacement. Only one compressed gas instrument was identified (Air Activator, Activator Methods International), which uses a valve to allow continuous adjustment of force magnitude between its minimal and maximal settings. Although many electromechanical instruments are available, we were able to identify only one capable of delivering single, noncyclic applications of force (Impulse, Neuromechanical Innovations, Phoenix, Ariz). This instrument uses an electric switch to select between 3 discrete force settings that act to control a solenoid, an electromagnetic device. Finally, to test

Table 2. *Standard deviations, expressed as a percentage of the mean value, of force durations generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings) and a manual technique. Also shown are force data generated by 4 different operators using a manual technique*

	% Deviation of mean force (N)			
	Expert 1	Expert 2	Novice 1	Novice 2
Activator IV*	5.059	2.778	2.596	2.771
Air Activator*	4.456	6.395	5.706	6.895
Impulse*	3.925	3.343	5.554	2.720
Signature*	2.961	2.557	2.613	4.270
	Expert A	Expert B	Novice A	Novice B
Manual	14.878	15.644	19.409	15.880
	% Deviation of mean duration (ms)			
	Expert 1	Expert 2	Novice 1	Novice 2
Activator IV*	7.309	2.608	5.960	6.519
Air Activator*	3.783	2.368	1.899	1.259
Impulse*	11.302	4.014	2.087	6.685
Signature*	5.600	3.994	5.376	2.935
	Expert A	Expert B	Novice A	Novice B
Manual	7.699	13.913	33.944	34.848

* $P \leq .05$ (significant difference).

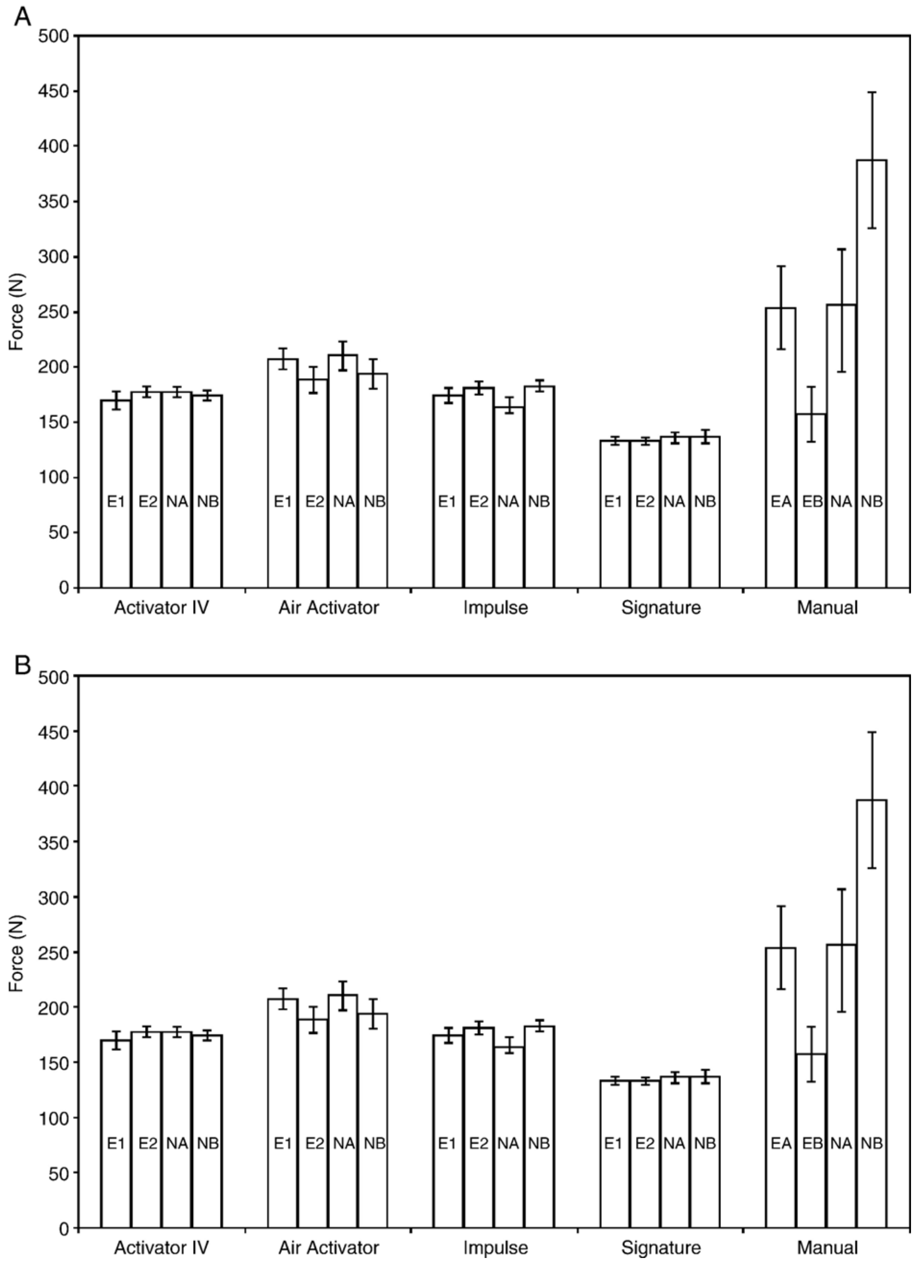

Fig 1. *A, Mean forces and SD bars of forces generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings) and 4 different operators (2 experts and 2 novices) using a manual technique. B, Log plot of mean force durations and SD bars of force durations generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings) and a manual technique. E1, Expert 1; E2, expert 2; N1, novice 1; N2, novice 2 (for instrument operators). EA, Expert A; EB, expert B; NA, novice A; NB, novice B (for manual operators).*

the performance between 2 of the same instruments, we selected a second spring-based device, the Activator Signature, which differs only from the Activator IV in its outward appearance.

Operators

Four individuals operated the 4 selected instruments. Two of the operators were considered to be "expert" as they use instrument-based force application in their practices on a daily basis and are certified in the use of Activator instruments by the manufacturer. The remaining 2 operators were considered to be "novice" as they do not use any of the instruments clinically nor are they certified to do so. Four different individuals (called operators for convenience) were selected to apply forces manually. Two operators were considered to be "expert" as they use manual force application techniques in clinical practice and are licensed

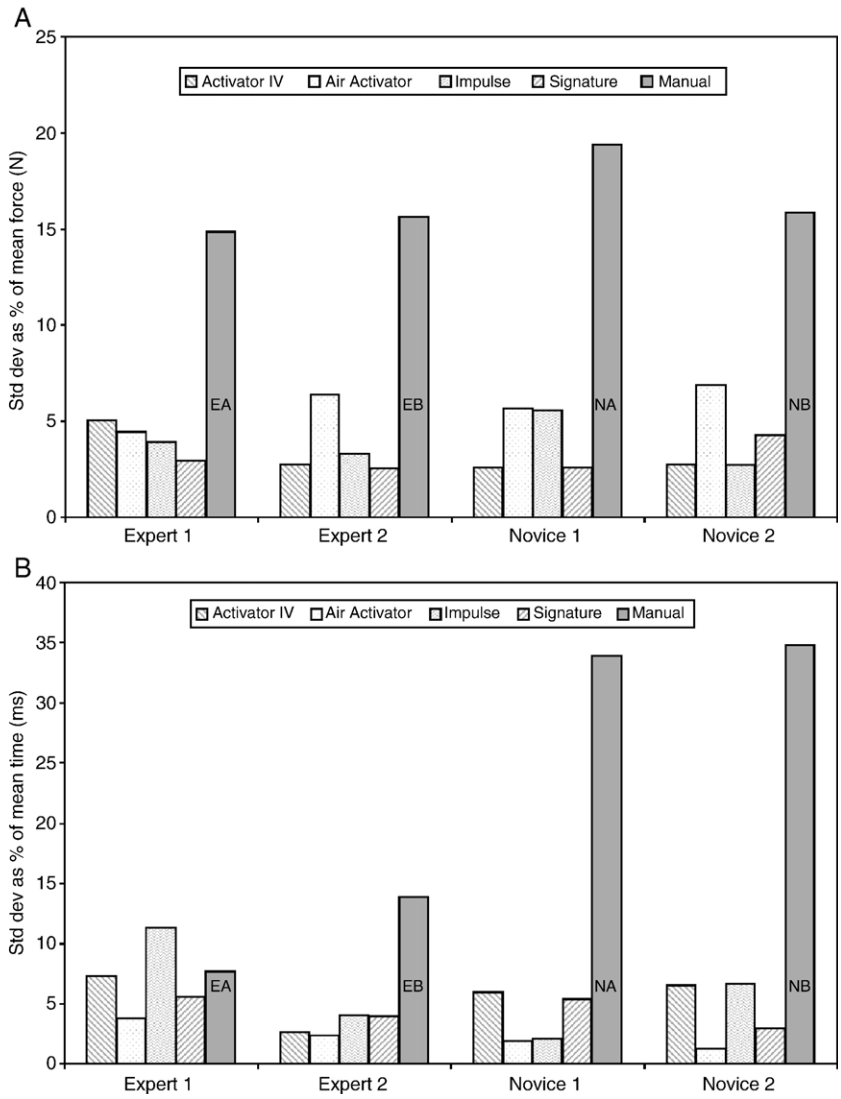

Fig 2. *A, Standard deviations of forces generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings) and 4 different operators (2 experts and 2 novices) using a manual technique expressed as percentages of the mean force for each operator/instrument combination. B, Standard deviations of force durations generated by 4 operators (2 experts and 2 novices) using 4 instruments (maximal force settings) and a manual technique (2 experts and 2 novices) expressed as percentages of the mean force duration for each operator/instrument combination.*

by their local jurisdiction to do so. The remaining 2 manual manipulators were considered to be "novice" as they did not possess training, experience, or licensure to perform manual applications of force.

Data Collection and Sensors

For the mechanical instruments, a single operator applied each instrument at its maximal force setting to a load cell (1 kN capacity, Measurement Specialties, Hampton, Va) fixed to a rigid surface. Each operator was allowed to practice using the instrument on the sensor before data collection. Specifically, a single operator used a single instrument at its maximal force setting to perform 10 applications of force at 5-second intervals. The remaining operators then used the same instrument in the same manner before the next instrument was tested. Because forces applied by instruments typically occur over short durations[26] and are not associated with concurrent increases in contact area,[27] a single sensor system (ie, load cell) was used to achieve an adequately high sampling rate. After calibration, force vs time data were collected by a 16-bit analogue to digital data collection system (National Instruments, Austin, Tex) at 50 kHz.

For manual force applications, each operator performed 10 force applications at 5-second intervals on a 10 × 10 sensor mat (each sensor 1 cm^2, Sensor Products Inc, Hanover, NJ) mounted on a rigid surface. All operators contacted the mat using a reinforced single hypothenar hand orientation. To have sufficient force magnitude reach the sensor, but not so great as to cause discomfort to the operator (given the rigid mounting of the sensor mat), operators were instructed to produce a "moderate" amount of force and were allowed to practice on the system before data collection. Because the force durations of manually applied forces[28] can be almost 2 orders of magnitude larger than those applied by instrument,[26] force-recording equipment with high sampling rates is not required. This permits use of multiplexed sensor matrices, which can characterize changes in contact area known to occur with manual force applications.[14] The multiple sensor mat used in this experiment was calibrated for a maximal pressure of 120 psi, and data were collected by the manufacturer's proprietary system at a maximal rate of 1000 Hz (Sensor Products Inc).

Variables

From the load cell and sensor mat data, 2 primary variables were collected: peak-to-peak force magnitude (N) and force duration (millisecond). Force magnitude was calculated after subtracting any preapplication force then taking the difference of force occurring over the ascending limb of the force-time plot. Force duration was computed by counting the number of data samples occurring in the ascending limb then dividing this figure by the collection rate.

Analysis

Variation analysis. For each primary variable (force and force duration), the mean value and SD were calculated for all 10 trials generated from each unique combination of instrument and operator (16 instrument combinations and 4 manual combinations). As a general measure of variability in the primary variables and to place the data in a common reference scale, SDs of each instrument/operator combination were expressed as a percentage of their associated mean value. In addition, Levene's test was used as a measure of intraoperator variability where a P value of more than .05 described insignificant between-operator differences in within-operator variation for a given instrument.

Absolute value comparison. To determine if different instrument operators generated different magnitudes of absolute force and force duration, we performed multiple comparisons on the primary variables for each operator pairing (6 possible) for each instrument or the manual technique. If Levene's test was insignificant (homogeneous within-operator variation), the Tukey post hoc analysis was performed; otherwise, if Levene's test was significant, the Tamhane post hoc analysis was performed.

Results

General Results

Manual applications of force were generally greater in force magnitude and force duration than those delivered by instrument (Table 1, Fig 1A and B). The mean force of all manual applications was 264 N with a mean force duration of 145 milliseconds. For all instrument applications, the average force was 171 N with an average force duration of 0.963 milliseconds.

Table 3. *P values of Levene's test for homogeneity of variation in force and duration data among all operators for 4 instruments (maximal force settings). Also shown are data for 4 different operators using a manual technique*

	Activator IV	Air Activator	Impulse	Signature	Manual
Force	0.654	0.513	0.331	0.189	0.09
Duration	0.185	0.103	0.004	0.531	0.01

Variation Analysis

While greater in magnitude, manual forces also displayed greater deviation from the mean value. On average, the SD for all manual applications represented 16% of the mean applied force and 23% of the mean force duration (Tables 1 and 2, Figs 1A-2B). For all instrument applications, the SD represented 4% of the mean applied force and 5% of the mean force duration (Tables 1 and 2, Figs 1A-2B).

Results for Levene's test pertaining to intraoperator variability are described in Table 3. For the force variable, the intraoperator variation for all instruments and the manual technique was found not to differ between operators. For force duration, the Impulse instrument and the manual technique were shown to have intraoperator variations that differed significantly between operators (P = .01 and P = .004, respectively).

Absolute Value Comparison

Multiple comparisons between any of 6 instrument operator pairings showed significant differences in the absolute force magnitudes and force durations produced (Table 4). For force magnitude, 9 of the 24 instrument operator comparisons (38%) were found to differ significantly ($P < .05$) in the absolute force produced. On further analysis, these differences were not found to be the result of any specific pairing of operators—significant differences in forces generated between expert operators with the same instrument were just as common as those between novice operators. In only one instrument, Activator IV, were all operators able to generate equal forces with 1 instrument. Similar results for instrument operators were observed for force durations (Table 5) where 18 of 24 between-operator comparisons (75%) were significantly different ($P < .05$). For force duration data, there were more significant differences between expert operators than between novices.

Table 4. *One-way analysis of variance of force magnitudes generated by 4 operators (2 experts and 2 novices) using 4 instruments and a manual technique used by 4 different operators*

	Force (N)						
	Overall	E1 vs E2	E1 vs N1	E1 vs N2	E2 vs N1	E2 vs N2	N1 vs N2
Activator IV*	0.024*	0.034*	0.044*	0.364	1.000	0.624	0.692
Air Activator*	0.000*	0.005*	0.923	0.062	0.001*	0.747	0.014*
Impulse*	0.000*	0.180	0.006*	0.048*	0.000*	0.919	0.000*
Signature*	0.075	1.000	0.253	0.253	0.213	0.213	1.000
	Overall	E1 vs E2	E1 vs N1	E1 vs N2	E2 vs N1	E2 vs N2	N1 vs N2
Manual	0.000*	0.000*	0.999	0.000*	0.000*	0.000*	0.000*

For instruments where intraoperator variation was homogeneous (Levene's test, Table 3), Tukey post hoc multiple comparison was performed (Activator IV, Air Activator, Signature); otherwise, Tamhane post hoc multiple comparison was performed (Impulse, Manual). *E1*, Expert 1; *E2*, expert 2; *N1*, novice 1; *N2*, novice 2 (for instrument operators). *EA*, Expert A; *EB*, expert B; *NA*, novice A; *NB*, novice B (for manual operators).

* $P \le .05$ (significant difference).

Table 5. *One-way analysis of variance of force durations generated by 4 operators (2 experts and 2 novices) using 4 instruments and a manual technique used by 4 different operators*

	Time (ms)						
	Overall	E1 vs E2	E1 vs N1	E1 vs N2	E2 vs N1	E2 vs N2	N1 vs N2
Activator IV*	0.000*	0.448	0.000*	0.000*	0.003*	0.000*	0.284
Air Activator*	0.000*	0.000*	0.974	0.000*	0.000*	0.000*	0.000*
Impulse*	0.000*	0.000*	0.998	0.975*	0.001*	0.000*	0.935
Signature*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*
	Overall	E1 vs E2	E1 vs N1	E1 vs N2	E2 vs N1	E2 vs N2	N1 vs N2
Manual	0.000*	0.503	0.001*	0.000*	0.044*	0.000*	0.000*

For instruments where intraoperator variation was homogeneous (Levene's test, Table 3), Tukey post hoc multiple comparison was performed (Activator IV, Air Activator, Signature); otherwise, Tamhane post hoc multiple comparison was performed (Impulse, Manual).

* $P \le .05$ (significant difference).

Discussion

As is the case in other investigations that have studied manual force application,[11,29-33] we observed large variation in force magnitude and force duration. In general, the manual technique generated much greater between-operator differences in mean absolute forces and force durations compared to instruments. This was expected as there can be no objective magnitude reference for manual operators to achieve other than instruction to provide some subjective level of force. This was also the case for SDs; the absolute SD for forces and force durations was generally greater for the manual technique compared to all instruments. It must be noted that comparison of absolute forces between instrument and manual methods is made difficult as the contact areas between the 2 approaches may differ.[27]

Given these results, we would expect that the use of an instrument would reduce human inconsistency and result in reduced variation in the primary variables. Specifically, we would expect that because the instrument has predefined force settings, the mean force generated between operators by any instrument should be much more similar than mean forces generated between manual operators who lack a common magnitude reference. Second, the use of a tool over a manual method should decrease output variability. To a large extent, these 2 expectations were met, but other considerations exist.

First, although the use of an instrument reduced variation in the mean force and force duration, there was not a complete elimination of variability. The fact that 2 almost identical instruments (Activator IV and Activator Signature) produced different results underscores this point. As seen in the multiple comparison analysis, absolute force generated by any 2 operators for a given instrument resulted in significant differences in 9 (38%) of 24 possible pairings. For force duration, this difference reached 75%.

These between-operator differences in absolute force parameters are most likely explained by variation in the application of the instrument, not through differences in the mechanism of the instrument. Although our data provide no direct proof that significant variation between instrument operators is the result of any specific factor, or that these factors occur globally in other instruments and operators, we observed that the angle of instrument inclination can change significantly between trials. Instrument angulation would act to decrease output in the load cell used in this experiment as any component of force that is not perpendicular to the surface of the load cell is lost in the load cell's output. It was also apparent from our observations, and in speaking with the operators, that it was possible to hold the instrument in ways that alter the operator's opposition to the instrument's recoil—a phenomenon we reproduced after data collection. Given these observations, we propose that these 2 factors, instrument angulation and opposition to instrument recoil, potentially influence the variability of force-producing instruments and may be the underlying reason for our observation that different operators can produce different results with the same instrument.

Second, the intraoperator variability for force magnitude, as measured by Levene's test, was found to be equal for any application method; the operators of the manual technique were just as variable in producing force as the instrument operators. What is not described by Levene's test is the magnitude of that variability. Therefore, intraoperator variation cannot be considered independently of the absolute magnitudes of variation. This is especially true if an absolute reduction in variation is needed to consistently achieve some clinically significant value.

Furthermore, given that it is generally accepted that manual techniques require training to acquire specific performance levels,[29,30,34] we unexpectedly observed equality in the intraoperator variability for force (including novice to expert comparisons). In only 2 cases was the intraoperator variability found to differ significantly between operators for the force duration generated by the Impulse instrument and the manual technique. At present, a satisfactory explanation for these observations is not available from our data.

The results from this work not only indicate that force-producing instruments may create different results in the hands of different operators, but they also imply that previous attempts to evaluate the performance of different instruments may be confounded by unreported variability within or between operators. It should be pointed out that differences in methodologies make it impossible to apply the results found in this study to reexamine the conclusions of prior studies. Therefore, statements that appear in academic journals[35,36] or manufacturer advertisements[37-39] that do not account for operator variability and claim specific instruments to be superior based on generating more force (or less) or reduced force durations (or increased) should be interpreted with caution.

Conclusion

Force-producing instruments reduce absolute variation in force magnitude and duration. This reduction is not so great as to eliminate significant differences in absolute force parameters observed to occur between some operators using the same instrument. The clinical significance of these results has yet to be determined. Given these observations, prior (and future) claims of instrument superiority, which do not account for interoperator variability, should be considered with caution.

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Practical Applications

- Compared to manual force techniques, instruments tended to reduce the variability in absolute force magnitude and force duration.
- Despite a general reduction in variability in instrument-based force production, the same instrument in the hands of different operators often produced significantly different values of absolute force, although the intraoperator variation was insignificant.
- For force duration, the intraoperator variation was significantly different in the manual technique and in one of the instruments tested.
- Claims of instrument superiority that do not account for interoperator variability or differences in absolute values generated by different operators should be considered with caution.

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