Bachelor's thesis

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Predicting one repetition maximum from the results of isometric strength tests

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Bachelor’s Thesis | Abstract

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Predicting one repetition maximum from the results of isometric strength tests

The objective of the thesis was to study whether maximum voluntary isometric contraction (MVIC) values can be converted to one repetition maximum values (1RM) with a high degree of reliability in order to develop a mathematical formula for the conversion. An additional objective was to examine the relationship between 1RM and isometric muscle strength using exercise devices.

The study participants comprised of healthy, trained men (n = 6) and women (n = 9). 1RM and MVIC tests were carried out at the Nordic Health clinic located in Helsinki using David Health Solutions’ exercise devices. Data was collected from 20 different exercises. The collected data was analyzed using Microsoft Excel and a statistical mathematics add-on.

As a result of this thesis, a strong correlation between 1RM and MVIC values was found (0,89). Additionally, a formula to estimate a person’s 1RM based on the results of the isometric muscle strength measurement was developed.

Keywords:

1RM, Isometric, MVIC, Algorithm, Exercise, Rehabilitation, Conversion

Opinnäytetyö | Tiivistelmä

Turun Ammattikorkeakoulu

Tieto- ja viestintätekniikka

2024 | 31

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Yhden toiston maksimiarvon ennustaminen isometrisen voimamittauksen tuloksista

Opinnäytetyön tarkoituksena oli tutkia yhden toiston maksimiarvojen (1RM) ja isometristen voimamittausten (MVIC) välistä korrelaatiota ja selvittää, voiko isometristen voimamittausten tuloksista ennustaa luotettavasti yhden toiston maksimiarvon. Lisäksi työn tavoitteena oli luoda matemaattinen kaava isometristen voimamittausten tulosten muuntamiseksi yhden toiston maksimiksi, mikäli riittävä luotettavuus voidaan osoittaa.

Tutkimukseen osallistujat olivat terveitä ja hyvässä fyysisessä kunnossa olevia miehiä (n = 6) ja naisia (n = 9). Tutkimuksessa tehdyt testit toteutettiin Helsingissä sijaitsevalla Nordic Health -klinikalla käyttäen David Health Solutions -laitevalmistajan G-line laitteita. Dataa kerättiin 20:stä eri lihaskuntoliikkeestä ja kerätty data analysoitiin Microsoft Excelin tilastotiede lisäosalla.

Opinnäytetyön tuloksena havaittiin vahva korrelaatio (0.89) 1RM- ja MVIC-arvojen välillä. Tulosten pohjalta kehitettiin matemaattinen kaava MVIC-arvon muuntamiseksi 1RM-arvoksi.

Keywords:

1RM, Isometrinen, MVIC, Kaava, Liikunta, Kuntoutus, Konversio

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List of abbreviations

1RM	One repetition maximum
BF	Body fat
BMI	Body mass index
MAE	Mean absolute error
MAPE	Mean absolute percentage error
MVIC	Maximum voluntary isometric contraction
ROM	Range of motion
R^2	Coefficient of determination, also known as goodness of fit
R	R-squared value, also known as correlation coefficient.
SD	Standard deviation
xRM	Repetition maximum for x repetitions. xRM refers to the weight a person can lift for x amount of continuous exercise repetitions

1 Introduction

Musculoskeletal rehabilitation and exercise therapy are considered increasingly important fields due to factors such as aging population, sedentary lifestyle, and longer life expectancy [1]. The advancements in rehabilitation technology have been significant in the past decade and they continue to develop. As rehabilitation devices become even more technologically advanced, there is a need for software and mathematical formulas to convert the generated data into readable formats.

The aim of this thesis is to investigate the relationship between maximum voluntary isometric contraction (MVIC) and one repetition maximum (1RM) values and create a precise mathematical formula to convert MVIC values to 1RM values. This conversion formula will be used when creating exercise programs for patients in rehabilitation setting. In addition, the accuracy of existing 1RM calculation formulas are evaluated in this thesis. This thesis was conducted in co-operation with David Health Solutions, and all measurements were conducted using their Generation line (G-line) devices.

The thesis is structured as follows:

Chapter 2 begins with an explanation of the purpose and background of 1RM and MVIC measurements, their common usage, and current challenges. Chapter 3 presents the research methods used in the thesis, including detailed information about the study protocol. Chapter 4 focuses on the analysis of the measurement data, exploration of the potential correlation between MVIC and 1RM values, and development of an algorithm to convert the former into the latter. Chapter 5 presents the results of the thesis and Chapter 6 includes the discussion of the results, accompanied by real-life examples highlighting the practical applications of the findings and a conclusion for the thesis.

2 Maximal strength measurement methods

Maximal strength measurement is widely used for evaluating physical performance and neuromuscular functionality. The most common methods used for measuring maximal strength are one repetition maximum (1RM) and maximum voluntary isometric contraction (MVIC).

2.1 One repetition maximum measurements

Repetition maximum (RM) values refer to the maximum weight a person can lift with a proper technique for a specific number of repetitions. The number before RM indicates the number of repetitions. For example, 1RM is the maximum weight for one repetition, and 7RM is the maximum weight for seven repetitions. To measure RM, the person being tested lifts as much weight as they can handle for 1-10 repetitions. If the number of repetitions is more than one, a formula must be used to convert the value into 1RM. [2]

1RM is often considered the “golden standard” of strength measurement due to the large amount of research and quantifiable results. In 1RM measurements eccentric actions are usually coupled with concentric actions giving a more accurate representation of the dynamic muscle actions used in strength training, general sports, and natural, everyday movement. [3]

The 1RM standard is also highly versatile and easy to adapt to different situations. It functions well for both simple and more complex exercises, single- and multi-joint movements without requiring expensive equipment and can be very space-efficient. As the 1RM measurements are also commonly performed using familiar movements, the need for familiarization and prior training are low especially in individuals who are already familiar with strength training. [3]

Relative loads (%1RM) can be used in strength training to set appropriate training intensities to design individualized training programs that target specific goals such as strength development or building muscular endurance. 1RM is also often used to give trainers a way to follow the effectiveness of the used training program and to help people set personal goals. [4]

While 1RM testing offers strong insight into an individual's maximal strength capabilities, it also poses certain weaknesses. One of the largest causes of concern is the increased risk of injury when performing 1RM tests with heavy weights and low repetitions especially in elderly population [5] [6]. This risk is the largest when improper technique is employed, especially in exercises involving free weights as opposed to exercise machines. [5]

Furthermore, the time-consuming nature of 1RM testing, especially when assessing maximum strength in a large number of participants, can present challenges. Additionally, when it comes to older patients, there appears to be a lack of consensus regarding the reproducibility of the results of 1RM testing. [6] Therefore, alternative means such as maximum voluntary isometric contraction testing is often used when assessing maximal strength.

2.2 Maximum voluntary isometric contraction measurements

Maximum voluntary isometric contraction (MVIC) is a method used to measure muscle strength and activity. During the test procedure, a subject is instructed to voluntarily produce a maximal isometric contraction for a given muscle group. In other words, there is no movement of the joint, but the tension is generated in the muscle. [7] Isometric measurements, along with 1RM, are commonly used to assess a person’s maximum force. These tests are often used in rehabilitation and sports to assess the participants’ maximum force and to design personalized training plans. [8] [9]

As with 1RM, MVIC testing is not without both strengths and weaknesses. MVIC testing is often highlighted by its simplicity, time-efficiency, and the high reproducibility achieved through well-standardized testing conditions. When compared with 1RM testing, MVIC tests are also found to have a high sensitivity to changes in patient strength while also being seen as a safer alternative that is also taxing on patients. [9] On the other hand, in the study by Katharine M.

Conable and Anthony L. Rosner it is suggested that MVIC may discriminate interval changes in muscle strength. According to their research, MVIC testing can be equipment intensive and is not practical for day-to-day monitoring of therapy. [10]

2.3 Converting MVIC values into 1RM

As MVIC measurements are an easy, safe, and fast way to measure strength, they are often used in rehabilitation settings. 1RM testing carries an elevated risk of injury, particularly for older patients or individuals with no experience in weightlifting. [11] However, in exercise therapy and strength training, 1RM values are still necessary as a reference point for exercise intensity. By converting the easier-to-measure MVIC values to 1RM, these tests can be performed efficiently while maintaining patient safety.

However, there are several challenges when converting isometric strength test values into dynamic 1RM values. 1RM typically measures an individual's maximum strength during dynamic movements while MVIC assesses maximum strength during static muscle contractions. Converting between these different muscle actions is not straightforward, as the muscle recruitment patterns and biomechanics vary. [12] 1RM values are also exercise-specific and may give different results depending on the movement pattern, equipment used, and range of motion. MVIC values aim to determine maximum force generation regardless of the exercise. [13]

1RM and MVIC also rely on different neural and biomechanical factors. 1RM performance depends on factors like muscle fiber type, muscle length-tension relationship, and neural drive during dynamic contractions. MVIC performance, on the other hand, depends on factors like motor unit recruitment, rate coding, and muscle pennation angle. Individuals may also respond differently to 1RM and MVIC measurements due to factors like muscle architecture, muscle fiber composition, training background, and motor control. [9] Converting between these measures requires an understanding of their relationships and adjustments for the specific context to ensure accurate comparisons.

K. Warneke et al. and K. Portilla-Cueto et al. have reported contradictory results concerning the reliability of MVIC-to-1RM-conversion [9] [14]. In the review published by K. Warneke et al., the results showed MVIC results as unreliable for determining 1RM due to MAPE and MAE between both measurement procedures being intolerably high [8]. Conversely, the study by K. Portilla-Cueto et al. found a strong correlation between 1RM and MVIC, enabling reliable conversions [14].

3 Materials and methods

3.1 Participants and study design

Participants of this study (n = 15) were recruited from the Nordic Health Clinic Ruskeasuo (Helsinki) and from the friends and family of the staff. To be included to the study, participants needed to be 18-30 years old, healthy, and trained or somewhat trained. Exclusion criteria included conditions and diseases that could cause danger to the participant, pain in the measured area, and other conditions which might influence the capacity to produce maximal force. Full list of exclusion criteria is found in Appendix 2. Participant characteristics are listed in Table 1.

Table 1. Information on participants.

Variable	***Male (N=6)***	***Female (N=9)***
Age (Years)	24.83 ± 2.4	24.22 ± 2.3
Height (cm)	180.5 ± 8.2	168.5 ± 5.5
Weight (kg)	73.75 ± 0.8	69.66 ± 6.6
BMI (kg/m2)	22.7 ± 2.1	24.4 ± 2.3
BF (%)	15.8 ± 8.4	27.12 ± 6.5
BF (kg)	12.06 ± 6.5	18.95 ± 6.7
Muscle mass (kg)	35.6 ± 4.1	23.45 ± 5.0

All variables are presented as mean ±SD.

A written informed consent was obtained from all participants before starting the study. The research method was chosen as comparative, as participants’ MVIC and 1RM values were compared and their correlation was analysed.

3.2 Measurements

Measurements were done in Nordic Health Ruskeasuo using David Health Solution's G-line devices (n = 17). The device list and number of measurements performed in each device is found in Appendix 1. The devices targeted main muscle groups in upper body, lower body, and spine.

3.2.1 Anthropometrics

Height of the participants was measured using InBody stadiometer (InBody BSM170B). The weight, body mass index, body fat percentage, body fat mass and muscle mass were measured using multifrequency bioelectrical bioimpedance analysis (InBody 770).

3.2.2 ROM measurements

The full range of motion (ROM) was determined in each device using the device's inbuilt ROM measurement function. The full ROM was used in 1RM measurements. Exceptions to this were made in back and neck devices (G110, G120, G130, G140, G150, G160), in which only 80% of the maximal ROM was used to maintain participant safety. ROM was recorded in degrees in isolated movements, and in centimeters in multi-joint movements.

3.2.3 MVIC measurements

Prior to MVIC testing, the participants performed a 5-minute cardio warmup with an upright ergometer. The participants were also advised to do 10-15 warm-up repetitions with very light weight to get familiar with the device. Isometric MVIC tests were conducted using the device's inbuilt isometric measurement function. The movement arm of the device was immobilized to a specific measurement position. This position is unique to each device depending on the joint in question. Prior to the test performance, the measurer instructed the participant on correct test technique. Once the test started, participants were instructed to apply maximum force against the immobilized movement arm by increasing the tension during the first 1-2 seconds into the maximum and then holding the tension constant for 3 seconds. The measurement was performed twice in each device, and the better result was chosen and recorded. The results were recorded as Newton meters (Nm) in isolated devices or Newtons (N) in multi-joint movements.

3.2.4 1RM measurements

The 1RM test protocol started with warm-up repetitions with a light weight (~50% of estimated 1RM) were performed to get familiar with the device and prevent any potential risk of injury during 1RM testing. After warm-up, a short 1–2-minute rest period followed, after which the weight was gradually increased by 5-10% for upper body and 10-20% for lower body after each successful repetition until the subject could not complete the selected repetition(s). The goal was to determine participants' 1RM within 4 trials with a rest period of 3-5 min between each set. The final weight lifted successfully was recorded as the absolute 1RM or multiple RM. All participants received verbal reinforcement during the effort. All repetitions were performed at the same speed and ROM.

In devices that targeted lower back muscles (G110, G120, G150) and neck muscles (G140, G160), 5RM measurements, instead of 1RM, were performed to ensure participant safety. For some participants, the weight stack of the devices was not sufficient for measuring the 1RM value directly. In such cases, 3RM, 5RM, 7RM, or 10RM values were measured instead. The measured RM values were then converted to 1RM. Measurements that exceeded 10 repetitions were excluded from the analysis (N = 3) as 1RM conversion formulas are found to be highly inaccurate beyond that point.

4 Data analysis and formula development

4.1 Data analysis

The raw test data was logged into Microsoft Excel for the data analysis. Microsoft Excel was selected as the primary tool for data analysis due to the author's previous experience with the software and the analytical capabilities that it provides. While tools such as MATLAB and GeoGebra were also taken into consideration, they were ultimately disregarded due to their complexity and the author's preferences.

In some cases, the full 1RM could not be measured. In these cases, the recorded RM values were converted to 1RM to aid with formula development and to compare correlations between 1RM and MVIC values. Various formulas are used for 1RM conversion, each with their strengths and weaknesses. In this thesis, the following formulas were used:

Lombardi’s formula [15]:

$$1RM = w * r^{0,1} \tag{3}$$

Epley’s formula [15]:

$$1RM = w\left(1 + \frac{r}{30}\right) \tag{4}$$

Bryzcki’s formula [15]:

$$1RM = w * \left(\frac{36}{37 - r}\right) \tag{5}$$

In each formula

w = weigh

r = number of repetitions

To reduce errors in each 1RM formula, an average of the three formulas were used in the final 1RM calculation. The formulas were chosen for their individual accuracies in various repetition amounts. Bryzcki's 1RM equation provides the highest 1RM value when more repetitions are performed while yielding the lowest value with fewer repetitions. Epley's formula provides average results in all repetition counts. Lombardi's formula, however, provides the highest 1RM values with fewer repetitions while providing the lowest values with more repetitions as depicted in Figure 1.

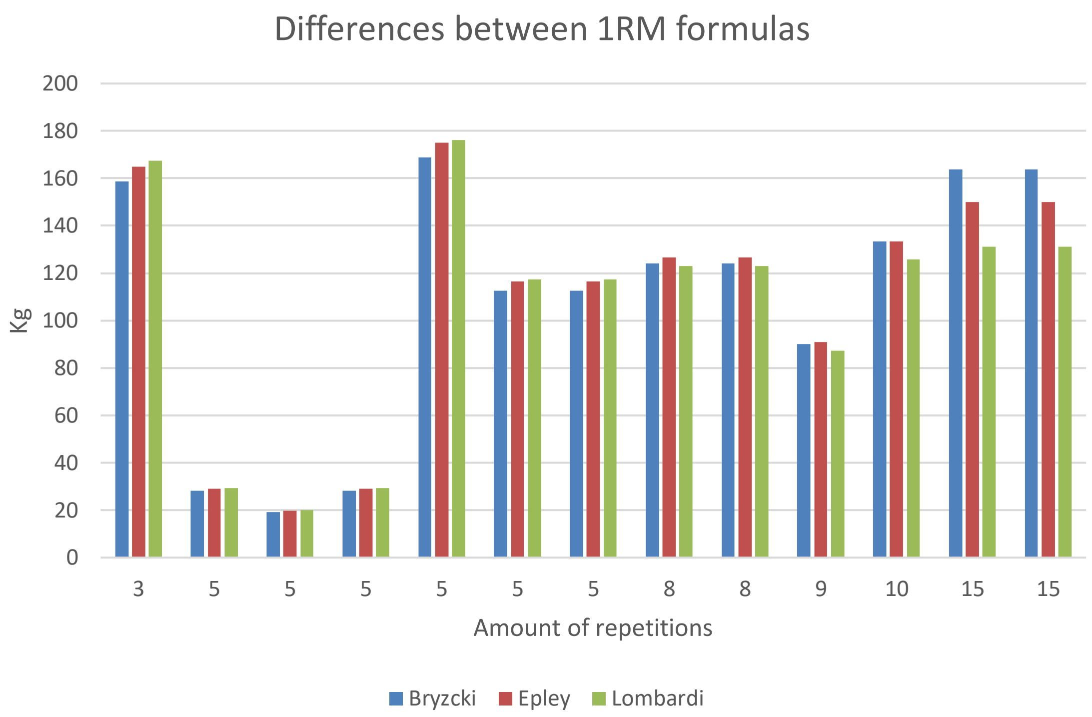

Figure 1: Differences between 1RM formulas.

Upon logging the test results into Microsoft Excel and transforming them into a workable format by converting RM-values to 1RM, the correlation between the converted 1RM and measured MVIC values was investigated. Initially, the separation of results based on gender was considered, but due to the limited number of participants, it was deemed impractical. This decision yielded a greater volume of data for analysis and helped make the correlation calculations more precise. However, it also led to an increased dispersion of results.

The correlation coefficient values were individually calculated for each device using Microsoft Excels CORREL function to the identification of a high overall correlation. Notably, as shown in Table 3., devices G150 and G120 showed a correlation coefficient of 1, signifying a flawless correlation. Although this finding initially raised suspicion, further examination confirmed the accuracy of the calculations and therefore these results were accepted.

4.2 Formula development

The formula development process began by conducting a regression analysis on the combined results of all device measurements. From these results, the intercept and MVIC coefficient values were collected (Table 2).

Table 2. MVIC and Intercept coefficients.

	Coefficients
Intercept	**23,32503406**
MVIC	**0,240670544**

These values were utilized in the basic regression algorithm [16]:

$$y = bx + a \quad (1)$$

Where:

y = 1RM

b = MVIC Coefficient

x = MVIC value

a = Intercept value

From these values, the following formula was created:

$$1RM = 0{,}24 * MVC + 23{,}32 \quad (2)$$

5 Results

5.1 Correlation between 1RM and MVIC

Overall, the correlation between MVIC and 1RM values was found to be strong (Table 3). Average Pearson correlation coefficient between MVIC and 1RM was found to be 0.89 with minimum and maximum values of 0.51 and 1.00.

Table 3. Correlations per device.

Correlation coefficient values per device

Device	Pearson Correlation Coefficient	Correlation
G110	1.00	Perfect
G120	0.98	Very strong
G130	0.95	Very strong
G140	0.87	Strong
G150	1.00	Perfect
G160	0.98	Very strong
G200	0.96	Very strong
G220	0.89	Strong
G260	0.64	Moderate
G300	0.92	Strong
G310	0.51	Moderate
G320	0.89	Strong
G420	0,93	Strong
G460	0.93	Strong
G510	0,88	Strong
G640	0.99	Very strong
G660	0.79	Strong

5.2 Formula development

As a result of this thesis, the following formula was created to aid in MVIC to 1RM conversion.

$$1RM = 0{,}24 * MVC + 23{,}32 \tag{2}$$

The formula was constructed using MVIC-coefficient and intercept values obtained from Microsoft Excel's regression analysis tool with the measured MVIC value. The R^2 value was found to be 0.70 meaning that the model explains 70% of the fitted data in the regression model.

As seen in Figure 2, the 1RM values derived from the formula and the ones measured and converted from the test data follow the measured 1RM closely with an average error of 24%. Largest differences between values can be observed in G220, G300, G310, G320, and G510 SCA.

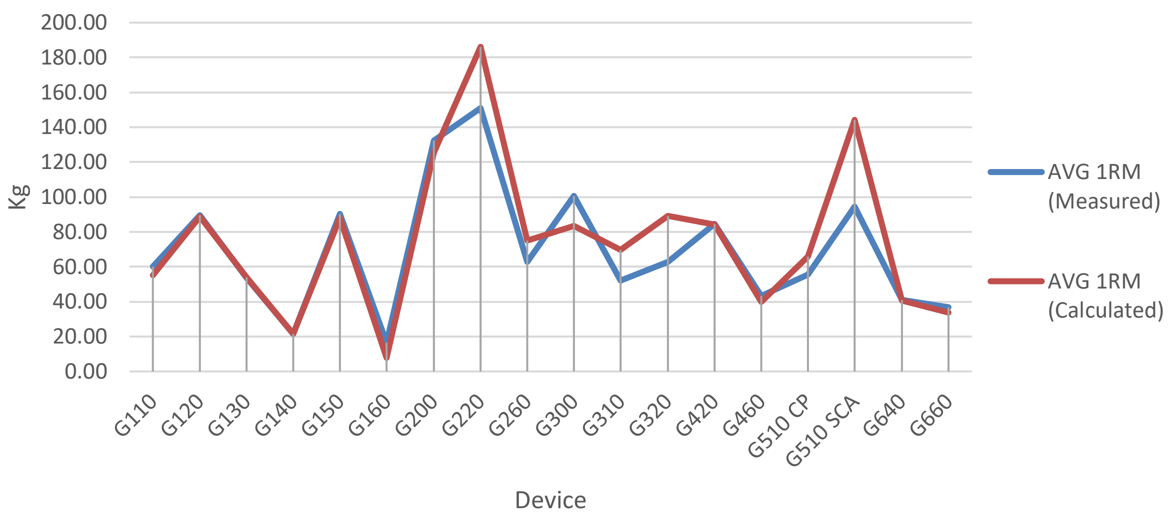

Figure 2. Differences between average calculated and measured 1RM per device.

To make the formula more precise in these devices, a device-specific modifier was added to the formula. This modifier was determined by comparing the differences between the 1RM result derived from the formula and the ones calculated using the three 1RM conversion formulas mentioned in chapter 4.

5.3 Validation of results

After a preliminary formula was created it was tested at the Nordic Health clinic. The testing process involved repeating the testing procedure from the initial tests with a shorter warmup period. As MVIC values were gathered, the created formula was used to convert it to 1RM. The MVIC data was also converted to

1RM using the existing data conversion formula currently used by David Health Solutions and was used to compare the two. For reference, proper 1RM tests were also conducted to see the value the formulas were trying to achieve. A clear increase in the accuracy was seen when using the new formula compared to the existing formula. However, the number of measurements for testing was small (n=3) so further testing may be necessary in the future.

6 Conclusions and further development

The aim of this thesis was to study the correlation between MVIC and 1RM values, and to investigate the reliability in predicting 1RM values from the results of MVIC measurements. In addition, the goal was to create a mathematical formula to convert the MVIC values into 1RM values.

6.1 Previous studies

As previous studies show, the reliability of converting MVIC values into 1RM values is considered contradictory. K. Portilla-Cueto et al. found possibilities in MVIC to 1RM conversion that closely align with the findings of this thesis, as shown in Table 4. [14] [9]

Table 4. Comparison between studies.

Variable	*Thesis*	*Study (K. Portilla-Cueto et al)*
R	0.89	0.87
R^2	0.70	0.80
Average error % of 1RM conversion	24%	12%

Their research found close correlation between MVIC and 1RM with a correlation coefficient of 0,87 versus the 0,89 achieved in this thesis. Although the results aligned closely, it must be noted that the participants of the study by K. Portilla-Cueto et al., of which 123 were men and 205 women, differed greatly in both number and their intrinsic qualities. In the study, all the participants also suffered from multiple sclerosis because of which only the leg muscles were used in the study. Multiple sclerosis can also have a profound effect on the overall functionality of the participants' nervous system which can have an effect on the final results. [9]

On the other hand, review by K. Warneke et al. raises questions about the reliability of only using regression and Pearson’s correlation coefficient for this type of conversion as regression and goodness of fit provide information on the relationships between the two variables but do not give information on the agreement or concordance of the differing testing procedures. The review states that to study replaceability of 1RM with MVIC testing, the concordance correlation coefficient (ρc) and the Bland-Altman analysis including the mean absolute error (MAE) and the mean absolute percentage error (MAPE) should be used instead of correlation coefficient. However, as a result of the review, the MAPE and MAE were found to be intolerably high and were deemed too inaccurate to give accurate conversions. [9]

6.2 Limitations

Overall, the small sample size in each device had a noticeable impact on the results. Because of the low number of measurements per device, some measurements were only taken with male or female participants, further impacting the results. Most of the participants were also young, healthy adults with some experience in weightlifting, so the accuracy of the formula on less fit and older people or people with health issues are still unknown. As 1RM and MVIC tests are mentally strenuous, measurers’ ability to motivate the participants for their best effort is also highlighted. Overall, four different measurers were performing the measurements which might have affected the results as well.

6.3 Further development

Although the results of this thesis seem to enhance MVIC-to-1RM conversion accuracy in the real-life applications, the results should be verified using a notably larger sample size. Future improvements could also involve diversifying participant demographics beyond young, fit, and healthy individuals. Additionally, further studies into the formula's applicability to multi-joint movements are recommended due to its current inaccuracy with such devices. As some evidence suggests, justifying the replaceability of 1RM testing with isometric testing based on correlation may be invalid. In the future it would be appropriate to use some other analysis methods such as concordance- and Bland-Altman analyses, to investigate the possibilities to replace 1RM testing with MVIC testing.

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Appendices

Appendix 1. Number of measurements per device.

Device	N
G110	5
G120	7
G130	6
G140 *	9
G150	5
G160	5
G200	6
G220	5
G260	6
G300	6
G310	5
G320	5
G420	8
G460	5
G510 / G520 *	8
G640	6
G660	5
Total measurements:	102

* Device enables multiple exercises. Number of measurements includes all of the exercises.

Exclusion Criteria

- Osteoporosis or a suspected case of Osteoporosis
- Osteopenia
- Fibromyalgia
- Degenerative neurologal illness
- Heart or lung condition demanding treatment
- Diabetes
- Metabolic syndrome
- Severe scoliosis
- Reactive arthritis
- Difficulty standing or walking independently
- Cancer
- High blood pressure
- Haematological disease (disease of the blood)
- Medication that affects muscle function (cytostatic, immunosuppressive)
- Metabolic syndrome
- Severe scoliosis
- Reactive arthritis
- Difficulty standing or walking independently
- Cancer
- High blood pressure
- Haematological disease (disease of the blood)
- Neuropathy
- Osteoarthritis
- Artificial joint
- Surgery or trauma in the measured area
- Chronic pain
- Pregnancy
- Smokers
- Neuropathy
- Osteoarthritis
- Artificial joint
- Surgery or trauma in the measured area
- Chronic pain
- Smokers

Appendix 2. Exclusion criteria.

G110 Lumbar / Thoracic Extension

G120 Lumbar / Thoracic Rotation

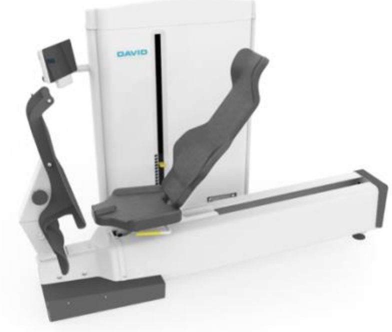
G130 Lumbar / Thoracic Flexion

G140 Cervical Extension / Lateral Flexion

G150 Lumbar / Thoracic Lateral Flexion

G160 Cervical Rotation

G200 Knee Extension



G220 Leg Press

G260 Hip extension

G300 Knee Flexion

G310 Hip Abduction

G320 Hip Adduction

G420 Pulldown

G460 Diagonal Shoulder Abduction

G510 Scapular Abduction / Chest Press

G640 Glenohumeral internal rotation

G660 Glenohumeral external rotation

Appendix 3. G-Line devices.