Scientific Principals and Clinical Application of the BioPrint: An Automated Biomechanical Assessment Tool

David H. McFarland[1,2,3]

Biotonix[1]
Université de Montréal[2], Faculté de médecine
Centre de recherche en sciences neurologiques
Institut de recherche en Gériatrie
McGill University[3], Faculty of Medicine

Introduction

Biotonix has marshaled basic scientific principals, on-going internal and externally supported research and key clinical installations to produce the BioPrint, an automated biomechanical assessment tool that uses cutting-edge, web-based technology to detect body alignment deviations and automatically generate personalized exercise programs. The BioPrint is listed as a Class I Medical Device with both Health Canada and the Food and Drug Administration of the United States of America, and patents are pending in Canada, the United States, and over 100 European and Asian countries.

This document provides a comprehensive summary of the biomechanical and clinical principals underlying this web-based tool. Past and ongoing research will be reviewed that supports the impact of the BioPrint on everyday life, performance, and health-related disorders.

Biomechanics: a Well-established scientific discipline

Biotonix has drawn on years of research supporting Biomechanics: the study of the mechanical characteristics of biological systems including the human body (e.g., Enoka, 2001; Winter, 1990). Biomechanics draws heavily from physics and applies principals originally used to describe the behavior of inanimate objects to an understanding of body form and function (e.g., Harrison, Janik, Troyanovich, and Holland, 1996; Troyanovich, Cailliet, Janik, Harrison, and Harrison, 1997; Troyanovich, Harrison, and Harrison, 1998). Biomechanics has a long and colorful history that can be traced back at least to Aristotle and his modeling of the impact of muscular action on the skeletal system (Enoka, 2001). It has matured into a well-established scientific discipline used within a wide range of academic domains including kinesiology, ergonomics, neuroscience and motor control.

The BioPrint employs the use of free body diagrams, a fundamental aspect of biomechanical analysis (Enoka, 2001), to assess the spatial orientation of body segments (e.g., head, trunk, and pelvis) and forces acting on the musculoskeletal system. Angular and distance measures are used to quantify body segment positions relative to horizontal and vertical plumb. Knowing the spatial orientation of the body segments provides an exceptionally rich body of data that can be used to determine a variety of fundamental biomechanical variables. Of particular relevance to the BioPrint, biomechanical assessment provides information about the interrelationships between the various body segments (i.e., how the position of the head is related to the position of the trunk), how the various body segments "deviate" from ideal alignment, compression forces acting on the spine and center of gravity estimates. These are all very well established measures of human form and function supported by a large body of scientific research (e.g., Andersson, 1985; Enoka, 2001; Harms-Ringdahl, Elkom, Schuldt, Németh, and Arborelius, 1986; Nachemson, 1965; Moroney, Schultz, and Miller, 1988; Nordin & Frankel, 1989; Snijders, Hoek Van Dijke, and Roosch, 1991; Winter, 1990). Normally, however, detailed biomechanical assessments are performed in research laboratories using expensive and elaborate technology that is difficult and time-consuming to use and interpret (For example, see Jensen, 1978.). If such tools are to be clinically supported and relevant, a much more streamlined technology would need to be established. The BioPrint meets these clinical demands.

Measurement of Biomechanical Variables

As illustrated in Apendix A, light reflective markers are placed at specific locations on the body that correspond to key underlying skeletal landmarks. These marker locations were chosen based on the widely accepted model of optimal and disordered posture provided by Kendall and others (Basmajian & De Luca, 1985; Griegel-Morris, Larson, Mueller-Klaus, and Oatis, 1992; Kendall, McCreary, and Provance, 1993). If these markers deviate from optimal (relative to horizontal and vertical plumb), we know that body segments and underlying skeletal structures are not optimally aligned. That is, there is a body alignment or postural deviation (Kendall et al. 1993).

After the markers are placed, four digital pictures are taken of the patient from the lateral, anterior, and posterior views in front of a calibrated backdrop. Three views are necessary for a complete postural assessment (Magee, 1997). The digital images are transferred to a personal computer where they are scanned to extract the anatomical coordinates of each marker. These data are sent to a central server via the web and proprietary software performs the detailed biomechanical analyses outlined above. These data are presented in tabular form in the BioPrint accompanied by images of patients/clients with the anatomical markers and body segments relative to horizontal and vertical plumb clearly illustrated.

Prioritization of Body Alignment Deviations

The calculated biomechanical variables are submitted to another stage of analysis to determine body alignment deviations that will be targeted for corrective exercise. An automated priority scaling is used to identify the most significant body alignment difficulties. Prioritization must be performed because many potential deviations can be detected, and there are a critical number of exercises to impact a particular deviation. It is known that patient compliance decreases significantly with excessively large numbers of corrective exercises because of the time required to complete the regime (Clark, 2001; Sevick, Dunn, Morrow, Marcus, Chen, and Blair, 2000). Consequently, the number of deviations must be limited to limit the number of corrective exercises.

The priority scheme developed for the BioPrint is based on two well-established clinical principles. The first being that the greater the deviation of a body segment from optimal, the more important its potential perturbing effects to overall postural stability. The second being that certain body segments have a relatively greater contribution to overall postural stability than others (O'Sullivan & Schmitz, 2001). We base our consideration of the contribution of body segments to overall postural stability on the well-established models of Kendall et al. and Watkins (Kendall et al. 1993; Watkins, 1996). These models consider the pelvis and trunk crucial to postural stability. Consequently, the trunk and pelvis have a Consequently, the trunk and pelvis have a relatively high priority in the BioPrint system compared to other postural deviations. So, the magnitude of the deviation of a body segment and its overall contribution to postural stability are determined and body alignment deviations are automatically selected by the system as targets for corrective exercise. It is important to note, however, that the selection of deviations made by the system (as well as the corrective exercises) can be overridden by the practitioner and alternative deviations (and exercises) selected depending on clinical judgments and case history. This emphasizes the role of the BioPrint as an adjunct to other diagnostic and treatment methodologies available to healthcare practitioners. The BioPrint's priority scaling of postural deviations is continuously monitored through our premier clinical installations such as those at Stanford University under the supervision of Drs. Don Chu and Gordon Matheson. Critical feedback from these clinics has revealed a close match between our automated deviation detection and clinical judgments. The deviations, either automatically identified or selected by the practitioner are displayed in the second portion of the BioPrint report.

One of the key components of the success of any system involving the placement of imaging markers is the ability of clinicians to consistently palpate underlying structural landmarks and accurately place markers overlying these anatomical locations. A study was completed at McGill University by Dr. David Pearsall to determine within and between tester reliability in marker placement and to determine the accuracy of the center of gravity estimates provided in the BioPrint relative to those measured by a force plate (a device that provides highly accurate measures of center of force or pressure). Dr. Pearsall is widely recognized for his biomechanical analyses of sport performance (Pearsall & Reid, 1994) and health-related conditions such as scoliosis (Pearsall, Reid, and Hedden, 1992). The results of this study indicated high reliability within and between examiners and the center of gravity estimate showed very high correlation to measures obtained by the force plate. An abstract (Woo & Pearsall, 2002) of this study was submitted to the upcoming IV Word Congress of Biomechanics conference in Calgary (in collaboration with the American and Canadian Biomechanics Societies) and an article was submitted for publication ().

Corrective Exercise Regime

Once the postural deviations are detected and prioritized, a series of corrective exercises are automatically generated and displayed in the third section of the BioPrint report. Our exercise treatment for postural deviations is based on the well-accepted model that deviations (of non-orthopedic origin) result from an imbalance of activation of antagonist muscles acting on joints (e.g., Higgs & Mackinnon, 1995; Janda, 1986). Some muscles are hyper contracted and some are hypo contracted giving rise to deviations from optimal alignment. The goal then is to strengthen the weak muscles and stretch the over-developed muscles (Janda, 1986; Watkins, 1996). Our specific stretching and strengthening exercises are developed internally and based on extensive clinical consultation (e.g., Harrison, Janik, Harrison, Troyanovich, Harrison, Harrison, 1996) and exercise physiology protocols provided by such authorities as the American College of Sport Medicine and the Canadian Society of Exercise Physiology.

Lower Back Pain

Further, our exercise regimes were recently evaluated and refined by Dr. Cheryl Hubley-Kozey of the Department of Physical Therapy of Dahlhousie University. Dr. Hubley-Kozey has published extensively on exercise protocols for musculoskeletal difficulties (e.g., Hubley-Kozey, Stanish, and Curwin, 1994; Hubley-Kozey, Wall, and Hogan, 1995a, 1995b). Further, Dr. Hubley-Kozey collaborated with Biotonix on an extensive review and synthesis of the most effective exercise treatments for lower back pain. This lead to a presentation and published abstract (McCulloch & McFarland, 2001) at the 4th Interdisciplinary World Congress on Low Back and Pelvic Pain in Montreal, and a paper summarizing these findings has been submitted for publication (). The exercises reviewed in this work that were found to be most effective for treating low back pain were incorporated into the already extensive database of corrective exercises of the BioPrint.

Posture and Pregnancy

Clearly, one group that may show increased risk of low back pain is women at different stages of pregnancy (Dumas, Reid, Wolfe, Griffin, and McGrath, 1995a, 1995b). This is because a women's morphology/postural form changes gradually and significantly during pregnancy, and changes in posture place additional stresses on the joints and spine (Jensen, Doucet, and Trietz, 1996; Moore, Dumas, and Reid, 1990; Ostgaard, Andersson, Schultz, and Miller, 1993). Postural changes that occur during pregnancy often remain postpartum and may continue to impact biomechanical form and function. The profound and often individualized changes in posture that occur prior to, during, and after pregnancy, therefore stresses the need for personalized postural assessments linked to preventative and rehabilitative corrective exercise protocols (Markel Feldt, 2000). The Society of Obstetricians and Gynaecologists of Canada in conjunction with Biotonix have incorporated personalized postural assessment (as provided by Biotonix) as part of their revised guidelines for exercise and pregnancy. These guidelines are scheduled to be introduced in the Spring of 2002. Further, exercises are currently being developed for the BioPrint that are safe and effective for pregnant women.

To adequately assess the biomechanical properties of women at different stages of pregnancy, it is crucial to have accurate body segment parameter data. Body segment parameters refer to variables such as percent contribution of a body segment (e.g., the trunk) to total body mass and the center of mass of particular body segments. Most biomechanical modeling employs data collected from older, adult males (e.g., Dempster, 1955), and these data clearly cannot be adequately applied to the rather extreme changes in body form that occur during pregnancy where, for example, the trunk mass increases during pregnancy due to the developing fetus (Jensen et al. 1996). A collaborative study under the direction of Dr. Geneviève Dumas was completed at Queen's University to establish body segment parameters necessary for modifying the BioPrint to assess postural deviations during pregnancy. Dr. Dumas is a leading authority of the biomechanical impact of pregnancy (e.g., Dumas et al. 1995a, 1995b). The findings from this study are invaluable for appropriate biomechanical assessment and corrective exercise intervention during pregnancy and are currently being integrated into the BioPrint. Specific corrective and preventative exercises for postural changes during pregnancy are being developed in parallel to these system modifications. The Biotonix system has the additional advantage that it is completely non-invasive, and can be used to track changes associated with pregnancy over repeated measurement periods.

Osteoporosis

Postural/biomechanical assessment plays an important role in aspects of women's health in addition to pregnancy. For example, osteoporosis is often associated with profound skeletal changes that place affected women at risk for fractures and other debilitating conditions (Sherman, 2001). One of the most common clinical manifestations of spinal osteoporosis is pronounced kyphosis of the thoracic spine (De Smet, Robinson, Johnson, and Lukert, 1988). Other postural complications include hyperlordosis of the lumbar spine and a more upright positioning of the sacrum (Satoh, Kasama, Itoi, Tanuma, and Wakamatsu, 1988). It is clear that postural assessment and training are valuable aspects of the detection and minimization of osteoporosis in susceptible adults. The application of the BioPrint for the identification and treatment of postural conditions associated with osteoporosis is being explored in collaboration with Baylor University Health Center. The general concept is a lifetime approach to postural assessment that could identify risk factors in early postmenopausal women. Again, the non-invasive characteristic of our system makes it an ideal and low-cost alternative to other imaging techniques. The exercise based correction component may improve patient's strength, flexibility, and coordination. All of these are key aspects of osteoporosis in affected patients.

Pediatrics

In addition to the aging population, biomechanical assessments and deviation identification is crucial for developing children. As was the case with pregnancy, body segment parameters associated with adults cannot accurately be applied to children if appropriate biomechanical assessments are to be made. Body segment proportions change significantly during development. For example, the head occupies approximately 18% of total body weight in the very young child (Jensen, 1986) compared to approximately 8% in the adult (Dempster, 1955). Applying parameters developed for adults may cause significant errors in the calculation of compression forces and center of gravity estimates. Fortunately, the scientific community has recognized the need for modified calculations for children and theoretical knowledge is available for appropriate biomechanical parameters for children (e.g., Jensen, 1986; Pheasant, 1986). Such information, however, must be integrated into clinical assessment protocols if accurate measures are to be provided. A systematic review of the available literature and data sets was completed to arrive at a consensus of appropriate biomechanical parameters for children. The focus is to use these data sets to adapt the center of gravity calculations and moment of force calculations for children of different developmental ages. An published abstract was presented to the upcoming IV Word Congress of Biomechanics conference (Woo & McFarland, 2002) summarizing this work. As was mentioned for pregnancy, repeated measures of the pediatric patients are required because of the rapid changes in musculoskeletal form and function during development. Consequently, a non-invasive measuring tool, such as the BioPrint is ideally suited for tracking the changes in young children's' posture and to assess the potential impact of clinical intervention. This may be particularly valuable for measurements of scoliosis in pediatric populations.

Quality of Life, Performance and Work-Related Applications of the BioPrint

In addition to the more global applications outlined above, the BioPrint provides a key analytical tool that has wide application in a variety of medical disciplines and for a variety of specific musculoskeletal conditions. Orthopedics, sports medicine, obstetrics and gynecology, physical and occupational therapy, chiropractic medicine, and ergonomics are some of the diverse medical and paramedical specialties that employ the BioPrint as a fundamental tool that complements other diagnostic and treatment methods. As such it has been applied to disorders consequent to accident (i.e., automobile accidents), orthopedic and work-related injuries, lower back pain, and sports and wellness contexts.

Biomechanical postural assessment is used routinely to assess the potential contribution of postural deviations to lower back and neck pain (e.g., see the Guide to Physical Therapy Practice by the American Physical Therapy Association [APTA], 1997). Body alignment difficulties such as forward head position and tilting of the pelvis increase the compression forces acting on the cervical and lumbar spine (Harms-Ringdahl et al. 1986; Nachemson, 1965; Moroney et al. 1988; Snijders et al. 1991) and may contribute to pain (Higgs et al. 1995; Griegel-Morris et al. 1992). These conditions can be exacerbated when heavy loads are involved (Omino & Hayashi, 1992; Vacheron, Poumarat, Chandezon, and Vanneuville, 1999).

Postural and biomechanical assessments are utilized routinely for ergonomic risk assessment protocols for work-related environments (Grieco, 1986; Higgs et al.1995; and see the Guide to Office Ergonomics from the Canadian Centre for Occupational Health and Safety [CCOHS], 2001). Certain postural deviations have been linked to job-related cumulative trauma disorders such as carpal tunnel syndrome (Pascarelli & Hsu, 2001). Much attention has been focused on the risk status of various occupations (e.g., Bonger, Hulshof, Dijkstra, and Boshuizen, 1990; Hamalainen, 1999; Magnusson, Wilder, and Areskoug, 1996). The exercises provided within the BioPrint that target postural deviations are applicable to work-related injuries such as repetitive stress disorders, and consequently, they may provide an important adjunct to other ergonomic and physical therapy assessment and treatment protocols (Hartig & Henderson, 1999; Higgs & Mackinnon, 1995).

In this regard, one of the most important clinical/scientific aspects of the BioPrint technology is its application in tracking a variety of musculoskeletal conditions resulting from disease and injury (APTA, 1997; Harrison, Janik, Harrison, et al. 1996). A comparative report can be generated that performs a contrast between any two BioPrints. Such a function is valuable, for example, for tracking progress in orthopedically or neurologically impaired patients subsequent to trauma (e.g., automobile accidents and work-related injuries). This provides a very valuable indicator of change over time and the potential impact of various treatment regimes, including surgical and non-surgical interventions.

Postural assessments are key to appropriate orthotic evaluation and prescription, as whole body posture influences forces and pressures acting on the feet (Cowan, Jones, Frykman, Polly, Harman, Rosenstein, and Rosenstein, 1996; Hertling & Kessler, 1990; Magee, 1990), and foot alignment may influence whole body posture (Hertling & Kessler, 1990; Magee, 1997). Appropriate foot alignment is of course very important to properly support skeletal alignment and distribute loads appropriately (Cowan et al. 1996; Reynolds, White, Knapik, Witt, and Amoroso, 1999).

Body alignment assessment and improvement also has very significant sports medicine and performance implications (Raine & Twomey, 1994; Watson, 2001). Postural deviations limit optimal performance in that the structural base from which movements are produced is not optimal and movements must compensate for these postural difficulties. The BioPrint has been used extensively with a variety of elite professional and Olympic athletes to restore postural symmetry and improve performance. One of the key aspects of attempting to develop symmetrical muscle development is the reduced risk of injury when excessive demands (such as high physical performance and stresses) are placed on the musculoskeletal system (Shambaugh, Klein, and Herbert, 1990; Cowan et al. 1996; Watson, 2001). Consequently, the career of an elite athlete may be prolonged by attention to preventative musculoskeletal maintenance.

Conclusion

The BioPrint represents a unique application of well-supported scientific principals to impact a wide range of musculoskeletal conditions. The impact of the BioPrint will continue to expand with clinical experience and consensus, consultation of the ever-widening scope of scientific literature, and the results of ongoing and future research.

References

American College of Sports Medicine. (2000). Guidelines for exercise testing and prescription (6th ed.). Philadelphia: Lippincott Williams & Wilkins.

American Physical Therapy Association. (1997). Guide to physical therapist practice. Physical Therapy, 77, 1213-1218.

Andersson, G. B. J. (1985). Posture and compressive spine loading: Intradiscal pressures, trunk myoeletric activities, intra-abdominal pressures and biochemical analysis. Ergonomics, 28, 91-93.

Basmajian, J. V., De Luca, C. J. (1985). Muscles alive: their functions revealed by electromyography (5th ed.). Baltimore: Williams & Wilkins.

Bérubé-Poliquin A., Woo T.K., Pearsall D.J., Prince F. (2002). Accuracy and inter/intra-tester reliability of biomechanical measures of the Biotonix Postural Analysis System. Article submitted to the Archives of Physical Medicine and Rehabilitation.

Bonger, P. M., Hulshof, C. T. J., Dijkstra, L., & Boshuizen, H. C. (1990). Back pain and exposure to whole-body vibration in helicopter pilots. Ergonomics, 33, 1007-1026.

Canadian Centre for Occupational Health and Safety. (2001). Office ergonomics (3rd ed.).

Clark, D. O. (2001). Issues of adherence, penetration, and measurement in physical activity effectiveness studies. Medical Care, 39, 409-412.

Cowan, D. N., Jones, B. H., Frykman, P. N., Polly, D. W., Harman, E. A., Rosenstein, R. M., & Rosenstein, M. T. (1996). Lower limb morphology and risk of overuse injury among male infantry trainees. Medicine and Science in Sports and Exercise, 28, 945-952.

Dempster, W. T. (1955). Space requirements of the seated operator. WADC Technical Report. Wright-Paterson Air Force Base, OH.

De Smet, A. A., Robinson, R. G., Johnson, B. E., & Lukert, B. P. (1988). Spinal compression fractures in osteoporotic women: Patterns and relationship to hyperkyphosis. Radiology, 166, 497-500.

Dumas, G. A., Reid, J. G., Wolfe, L. A., Griffin, M. P., & McGrath, M. J. (1995a). Exercise, posture, and back pain during pregnancy. Part 1. Exercise and posture. Clinical Biomechanics, 10, 98-103.

Dumas, G. A., Reid, J. G., Wolfe, L. A., Griffin, M. P., & McGrath, M. J. (1995b). Exercise, posture, and back pain during pregnancy. Part 2. Exercise and back pain. Clinical Biomechanics, 10, 104-109.

Enoka, R. M., (2001). Neuromechanics of human movement (3rd ed.). Champaign: Human Kinetics.

Grieco, A. (1986). Sitting posture: An old problem and a new one. Ergonomics, 29, 345-362.

Griegel-Morris, P., Larson, K., Mueller-Klaus, K., & Oatis, C. A. (1992). Incidence of common postural abnormalities in the cervical, shoulder and thoracic regions and their association with pain in two age groups of healthy subjects. Physical Therapy, 72, 425-431.

Hamalainen, O. (1999). Thoracolumbar pain among fighter pilots. Military Medicine, 164, 595-596.

Harms-Ringdahl, K., Ekholm, J., Schuldt, K., Németh, G., & Arborelius, U. P. (1986). Load moments and myoelectric activity when the cervical spine is held in full flexion and extension. Ergonomics, 29, 1539-1552.

Harrison, D. D., Janik, T. J., Troyanovich, S. J., & Holland, B. (1996). Comparisons of lordotic cervical spine curvatures to a theoretical ideal model of the static sagittal cervical spine. Spine, 21, 667-675.

Harrison, D. D., Janik, T. J., Harrison, G. R., Troyanovich, S. J., Harrison, D. E., & Harrison, S. O. (1996). Chiropractic biophysics technique: A linear algebra approach to posture in chiropractics. Journal of Manipulative and Physiological Therapeutics, 19, 525-535.

Hartig, D. E., & Henderson, J. M. (1999). Increasing hamstring flexibility decreases lower extremity overuse injuries in military basic trainees. American Journal of Sports Medicine Abstract, 27, 173-176.

Hertling, D., & Kessler, R. M. (1990). Management of common musculoskeletal disorders (2nd ed.). Philadelphia: J.B. Lippincott.

Higgs, P. E., & Mackinnon, S. E. (1995). Repetitive motion injuries. Annual Review of Medicine, 46, 1-16.

Hubley-Kozey, C. L., Stanish, W. D., Curwin, S. L. (1994). Rehabilitation principles and techniques. In J. C. DeLee and D. Drez, Jr. (Eds.), Orthopaedic and sport medicine principles and techniques: Vol. 1 (pp. 184-202). Philadelphia: W. B. Saunders.

Hubley-Kozey, C. L., Wall, J. C., Hogan, D. B. (1995a). Effects of a general exercise program on passive hip, knee and ankle range of motion of older women. Topics in Geriatric Rehabilitation, 10, 33-44.

Hubley-Kozey, C. L., Wall, J. C., Hogan, D. B. (1995b). Effects of a general exercise program on plantar flexor and dorsiflexor strength and power of older women. Topics in Geriatric Rehabilitation, 10, 45-60.

Janda, V. (1986). Muscle weakness and inhibition (pseudoparesis) in back pain syndromes. In G. P. Grieve (Ed.), Modern manual therapy of the vertebral column (pp. 197-201). New York: Churchill Livingstone.

Jensen, R. K., (1978). Estimation of the biomechanical properties of three body types using a photogrammetric method. Journal of Biomechanics, 11, 349-358.

Jensen, R. K., (1986). Body segment mass, radius and radius of gyration proportions of children. Journal of Biomechanics, 19, 359-368.

Jensen, R. K., Doucet, S., & Treitz, T. (1996). Changes in segment mass and mass distribution during pregnancy. Journal of Biomechanics, 29, 251-256.

Kendall, F. P., McCreary, E. K., & Provance, P. G. (1993). Muscle testing and function (4th ed.). Baltimore: Williams and Wilkins.

Magee, D. J. (1997). Orthopedic physical assessment (3rd ed.). Philadelphia: W. B. Saunders.

Magnusson, M. L., Pope, M. H., Wilder, D. G., & Areskoug, B. (1996). Are occupational drivers at an increased risk for developing musculoskeletal disorders? Spine, 21, 710-717.

Markel Feldt, C. (2000). Applying the guide to Physical Therapist practice to women's health physical therapy: Part II. Journal of the Section on Women's Health, 24

McCulloch, T., & McFarland, D. H. (2001). Exercise therapies for low back pain: A critical review. 4th Interdisciplinary world congress on low back and pelvic pain, Montreal, Quebec. 439.

Moroney, S. P., Shultz, A. B., & Miller, J. A. A. (1988). Analysis and measurement of neck loads. Journal of Orthopaedic Research, 6, 713-720.

Moore, K., Dumas, G. A., & Reid, J. G. (1990). Postural changes associated with pregnancy and their relationship with low-back pain. Clinical Biomechanics, 5, 169-174.

Nachemson, A. (1965). The effect of forward leaning on lumbar intradiscal pressure. Acta Orthopedica Scandinavia, 35, 314-328.

Nordin, M., & Frankel, V. H. (1989). Biomechanics of the lumbar spine. In Wiliams & Wilkins (Ed.), Basic biomechanics of the musculoskeletal system (pp. 183-207). Philadelphia, PA: Lea & Febiger.

Omino, K., & Hayashi, Y. (1992). Preparation of dynamic posture and occurrence of low back pain. Ergonomics, 35, 693-707.

Ostgaard, H. C., Andersson, G. B. J., Schultz, A. B., & Miller, J. A. A. (1993). Influence of some biomechanical factors on low-back pain in pregnancy. Spine, 18, 61-65.

O'Sullivan, S. B., & Schmitz, T. J. (2001). Physical rehabilitation : Assessment and treatment (4th ed.). Philadelphia: F.A. Davis.

Pascarelli, E. F., & Hsu, Y. P. (2001). Understanding work-related upper extremity disorders: Clinical findings in 485 computer users, musicians, and others. Journal of Occupational Rehabilitation, 11, 1-21.

Pearsall, D. J., & Reid, G. (1994). The study of human body segment parameters in biomechanics: An historical review and current status report. Sports Medicine, 18, 126-140.

Pearsall, D. J., Reid, G., & Hedden, D. M. (1992). Comparison of three noninvasive methods for measuring scoliosis. Physical Therapy, 72, 648-657.

Pheasant, S. T. (1986). Bodyspace : Anthropometry, ergonomics and design. London: Taylor & Francis.

Raine, S., & Twomey, L. (1994). Attributes and qualities of human posture and their relationship to dysfunction or musculoskeletal pain. Critical Reviews in Physical and Rehabilitation Medicine, 6, 409-437.

Reynolds, K. L., White, J. S., Knapik, J. J., Witt, C. E., & Amoroso, P. J. (1999). Injuries and risk factors in a 100-mill (161-km) infantry road march. Preventive Medicine, 28, 167-173.

Satoh, K., Kasama, F., Itoi, E., Tanuma, S., & Wakamatsu, E. (1988). Clinical features of spinal osteoporosis: Spinal deformity and pertinent back pain. Contemporary Orthopaedics, 16, 23-30.

Sevick, M. A., Dunn, A. L., Morrow, M. S., Marcus, B. H., Chen, G. J., & Blair, S. N. (2000). Cost-effectiveness of lifestyle and structured exercise interventions in sedentary adults: results of project ACTIVE. American Journal of Preventive Medicine Abstract, 19, 1-8.

Shambaugh, J. P., Klein, A., & Herbert, J. H. (1991). Structural measures as predictors of injury in basketball players. Medicine and Science in Sports and Exercise, 23, 522-527.

Sherman, S. (2001). Preventing and treating osteoporosis: Strategies at the millennium. Annals of the New York Academy of Sciences, 949, 188-197.

Snijders, C. J., Hoek Van Dijke, G. A., & Roosch, E. R. (1991). A biomechanical model for the analysis of the cervical spine in static postures. Journal of Biomechanics, 24, 783-792.

Troyanovich, S. J., Harrison, D. E., Harrison, D. D. (1998). Structural rehabilitation of the spine and posture: Rationale for treatment beyond the resolution of symptoms. Journal of Manipulative and Physiological Therapeutics, 21, 37-50.

Troyanovich, S. J., Cailliet, R., Janik, T. J., Harrison, D. D., & Harrison, D. E. (1997). Radiographic mensuration characteristics of the sagittal lumbar spine from a normal population with a method to synthesize prior studies of lordosis. Journal of Spinal Disorders, 10, 380-386.

Vacheron, J. J., Poumarat, G., Chandezon, R., & Vanneuville, G. (1999). The effect of loads carried on the shoulders. Military Medicine, 164, 597-599.

Watkins, R. G. (1996). Muscle imbalance patterns associated with low back syndromes. In R.G. Watkins (Ed.), The spine in sports (pp. 146-156). St. Louis: Mosby-Year Book Inc.

Watson, A.W. S. (2001). Sports injuries related to flexibility, posture, acceleration, clinical defects and previous injuries, in high level players of body contact sports. International Journal of Sports Medicine, 22, 222-225.

Winter, D. A. (1990). Biomechanics and motor control of human movement. New York: John Wiley & Sons.

Woo, T. K., & McFarland, D. H. (2002). Adapting body segment parameters for biomechanical calculations with children. Abstract submitted to the IV World Congress of Biomechanics.

Woo, T. K., & Pearsall, D. J. (2002). Postural estimates from digital images: Inter-and Intra-tester reliability. Abstract submitted to the IV World Congress of Biomechanics.

Appendix A: The BioPrint Process

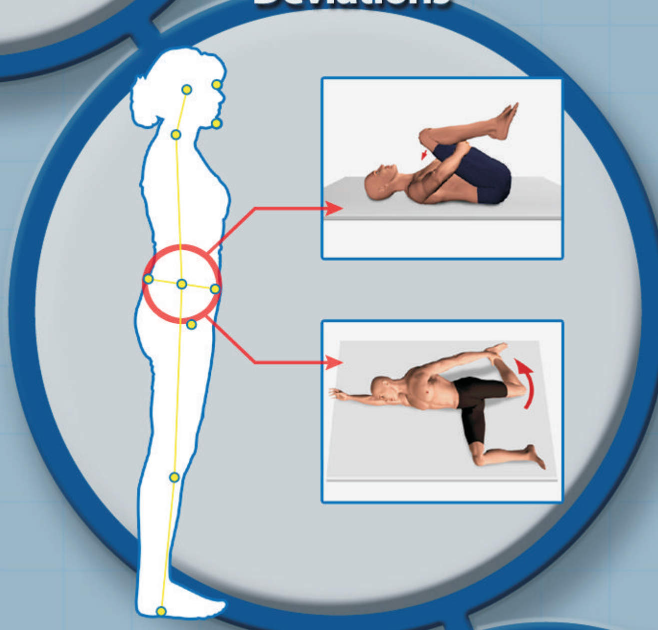
BIOTONIX
iHealth Solutions

THE PROCESS

Acquiring the Pictures

Analyzing the Posture

Detecting and Correcting Deviations



Tracking Progress